PROCEEDINGS OF THE ROYAL INSTITUTION OF GREAT BRITAIN

Vol. 38 Part I No. 170

1960

Containing accounts of the
FRIDAY EVENING DISCOURSES
and other meetings

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Proceedings of the

GENERAL MONTHLY MEETINGS

of the

Members of the Royal Institution

held during 1959

and the

Annual Meeting 1959

Printed as an inset to

PROCEEDINGS OF THE ROYAL INSTITUTION, 1960

Vol. 38 Part I No. 170

GENERAL MONTHLY MEETING

Monday, 2 February 1959

THE RIGHT HON. LORD BRABAZON OF TARA,
P.C., G.B.E., M.C.
President, in the Chair

Major N. P. Dawnay
G. G. Gouriet
H. W. Langford
P. N. Slater

were elected Members of the Royal Institution.

MEMBERS DECEASED

The Secretary announced the decease of the following Members:—

Miss Clare Helen Jameson
Mrs. E. M. Neal
Air Vice-Marshal D'Arcy Power

ASSOCIATE SUBSCRIBERS

The Chairman reported that the Managers had elected the following Associate Subscribers:—

Michael R. Arbon
Richard H. Arthure
Michael John Long
Peter B. Moody
Miss D. E. A. Schuftan
Miss Jennifer Stanesby
Miss J. M. Warren

ALTERATION TO BYE-LAW REGARDING INVESTMENTS

The proposal to amend Chapter XI Article 5 of the Bye-Laws regarding investments, which had been approved at the previous Meeting, was put to the Meeting and carried unanimously.

PRESENTS TO THE LIBRARY

The presents received since the last Meeting were laid on the table and the thanks of the Members returned for the same:—

H. Baines—The science of photography, by H. Baines, 1958. (2 copies).

British Broadcasting Corporation—B.B.C. handbook 1959.

Messrs. Fawcett, Preston & Co.,—"Fossetts", by H. White. 1958.

G. Parr, M.I.E.E.—The technical writer, by J. W. Godfrey and G. Parr. 1959.

Lieut. Col. H. R. Rishworth, C.B.E., F.R.C.S.—Giant fishes, whales and dolphins, by J. R. Norman and F. C. Fraser. 1937.

S. Robson, M.R.I.—A history of the chemical industries in Widnes, by D. Hardie. 1950.

Yale University,—The transuranium elements, by G. T. Seaborg. 1958.

GENERAL MONTHLY MEETING

Monday, 2 March 1959

THE RIGHT HON. LORD BRABAZON OF TARA, P.C., G.B.E., M.C.

President, in the Chair

W. J. Bray
Miss A. Burnard
Professor S. Chatterjee
G. R. Cooper
P. Daly
Miss G. O. Garton
F. J. Hackett
J. A. Harrison
J. E. T. Horne
C. A. Marshall
Miss I. N. C. McCrea
Yehudi Menuhin
Miss J. D. Murray
Dr. R. H. Smith
Professor F. A. Vick

were elected Members of the Royal Institution.

MEMBERS DECEASED

The Secretary announced the decease of the following Members:—

W. J. Picken
W. C. Slater

ASSOCIATE SUBSCRIBERS

The Chairman reported that the Managers had elected the following Associate Subscribers:—

Miss Gillian E. Cooper
Ronald Horn
Richard C. M. Learner

CORPORATE SUBSCRIBER

The Chairman reported that the Managers had elected the following Corporate Subscriber:—

Triplex Safety Glass Co., Ltd.

ALTERATION TO BYE-LAW REGARDING INVESTMENTS

The proposed alteration to Chapter XI Article 5 of the Bye-Laws, which had been approved at the previous Meeting, was duly confirmed.

GENERAL MONTHLY MEETING

Monday, 6 April 1959

THE RIGHT HON. LORD BRABAZON OF TARA, P.C., G.B.E., M.C.

President, in the Chair

B. Deutsch
D. E. L. Haynes
N. S. Hobday
Miss M. R. Jolowicz
W. K. B. Marshall
Sir Harry Melville
Dr. Helen Scouloudi
K. W. Shipman
D. J. Templeton

were elected Members of the Royal Institution.

MEMBERS DECEASED

The Secretary announced the decease of the following Members:—

Professor J. T. McGregor-Morris
Frank Twyman

ASSOCIATE SUBSCRIBER

The Chairman reported that the Managers had elected the following Associate Subscriber:—

Mrs. Elspeth Bruce Smith

LIBRARY SUBSCRIBER

The Chairman reported that the Managers had elected the following Library Subscriber:—

J. N. F. Morris

CORPORATE SUBSCRIBER

The Chairman reported that the Managers had elected the following Corporate Subscriber:—

British Nylon Spinners, Ltd.

NOMINATION OF PROFESSORS

The Chairman gave notice that the Managers had nominated Sir Harold Spencer Jones, K.B.E., Sc.D., F.R.S., as Professor of Astronomy, and Professor Ronald King, B.Sc., Ph.D., as Professor of Metal Physics, for election at the next General Monthly Meeting.

PRESENTS TO THE LIBRARY

The presents received since the last Meeting were laid on the table and the thanks of the Members returned for the same:—

C. M. Cade, M.R.I.—Radio-astronomy and navigation, by C. M. Cade. 1959.
Bern Dibner—The Atlantic cable, by Bern Dibner. 1959.

ANNUAL MEETING

Friday, 1 May 1959

THE RIGHT HON. LORD BRABAZON OF TARA, P.C., G.B.E., M.C.
President, in the Chair

The Annual Report of the Committee of Visitors and the Statement of Accounts for the year 1958 were presented by the Chairman of the Visitors, Mr. G. Parr, who drew attention to a number of points. He referred to the Secretary's Report which was included for the first time; to the Discourses and Lectures, especially those to school children; to the reorganisation of the Library; and to Sir Lawrence Bragg's part in the Brussels Exhibition.

Lord Brabazon referred to the close co-operation between the Visitors and Managers, and expressed thanks for the way in which the Visitors had carried out their duties during the year.

It was resolved that the Annual Report of the Visitors and the Statement of Accounts for the year 1958 be approved and adopted. [The Report is published in full in the *Record of the Royal Institution*, 1959].

Sir Lawrence Bragg presented his Report for the year 1958. He referred to a grant of about £43,000, to be spread over five years, which the National Institutes of Health in America had given for research; to the debt of gratitude owed to Professor King for his work in connection with the rebuilding of the Cornice; to the improved arrangements in the Lecture Theatre and apparatus stores; to the change in frequency of publication of the *Proceedings;* and expressed his appreciation of the work of C. C. Jackson, the Resident Electrician, and to the maintenance staff, especially T. J. Ryan, the Head Porter, and Mrs Parker.

Sir Lawrence, in referring to his five year's stewardship, spoke of what had been gained by experience and what remains to be planned. The greatest difficulty had been the financial position. Finally Sir Lawrence expressed his gratitude for the assistance he had received from Professor King in all the various activities of the Institution.

The following were elected Officers for the ensuing year:—

President—The Right Hon. Lord Brabazon of Tara, P.C., G.B.E., M.C.
Treasurer—W. E. Schall, B.Sc., F.Inst.P.
Secretary—Sir Harold Spencer Jones, K.B.E., Sc.D., F.R.S.

Managers

T. E. Allibone, D.Sc., Ph.D., F.R.S.
H. D. Anthony, M.A., B.Sc., Ph.D.
F. G. Brown
A. G. Gaydon, D.Sc., F.R.S.
Professor A. Haddow, M.D., D.Sc., Ph.D., F.R.S.
Mrs. H. K. Hawkes, M.Sc., F.G.S.
H. Heywood, D.Sc., Ph.D.
R. Holroyd, M.Sc., Ph.D.
E. Ironmonger
Professor L. A. Jordan, C.B.E., D. Sc., F.R.I.C.
James Lawrie
Sir Ben Lockspeiser, K.C.B., D.Sc., F.R.S.
J. A. Oriel, C.B.E., M.C., M.A., B.Sc.
H. P. Rooksby, B.Sc., F.Inst.P.
P. H. Schwarzschild

Visitors

A. D. Baynes-Cope, M.A., B.Sc.
Professor H. Dingle, D.Sc., A.R.C.S., D.I.C.
D. H. Follett, M.A., Ph.D., F.Inst.P.
A. J. Haselfoot, M.A.
S. Rees Jones, M.Sc., F.Inst.P.
W. C. Lister, B.Sc., M.I.E.E., F.Inst.P.
Miss C. M. McDowell, Ph.D.
Mrs. J. E. Milton, B.Sc.
F. A. Mitchell
N. P. W. Moore, D.Sc., D.I.C.
J. D. Peattie, C.B.E., B.Sc., M.I.E.E.
F. Y. Poynton, M.Sc., F.Inst.P.
Neville Shepherd
P. C. Spensley, M.A., B.Sc., D.Phil., F.R.I.C.
Norman Stuart, Ph.D., B.Sc., D.I.C

GENERAL MONTHLY MEETING

Monday, 4 May 1959

THE RIGHT HON. LORD BRABAZON OF TARA, P.C., G.B.E., M.C.
President, in the Chair

Professor C. R. Adams
G. P. Gowlland
J. Grant
F. Greenaway
W. W. H. Hill-Wood
F. A. Julian
B. P. Levitt
Mrs. M. Margulies
Dr. D. McMullan
D. J. Power
N. C. Taylor

were elected Members of the Royal Institution.

ELECTION OF PROFESSORS

In accordance with the nominations made at the previous Meeting, Sir Harold Spencer Jones, K.B.E., Sc.D., F.R.S. was re-elected Professor of Astronomy, and Professor Ronald King, B.Sc., Ph.D. was re-elected Professor of Metal Physics.

MEMBERS DECEASED

The Secretary announced the decease of the following Members:—

Sir William Larke
Professor L. A. Mayer
Major Charles Mitchell

VICE-PRESIDENTS FOR 1959–60

The Chairman announced that he had appointed the following Managers to serve in the office of Vice-President for the year 1959–60:—

Dr. H. D. Anthony
Dr. A. G. Gaydon
Dr. H. Heywood
Professor L. A. Jordan
Mr. James Lawrie
Mr. P. H. Schwarzschild
Mr. W. E. Schall, *Treasurer*
Sir Harold Spencer Jones, *Secretary*

ASSOCIATE SUBSCRIBER

The Chairman reported that the Managers had elected the following Associate Subscriber:—

Brian H. Unsworth

LIBRARY SUBSCRIBER

The Chairman reported that the Managers had elected the following Library Subscriber:—

J. D. Roberts

CORPORATE SUBSCRIBERS

The Chairman reported that the Managers had elected the follwing Corporate Subscribers:—

Imperial Tobacco Co., Ltd.
Richard Thomas & Baldwins, Ltd.
Thermal Syndicate, Ltd.

LEGACY

The Chairman reported that a further sum of £338 14*s*. 4*d*. had been received in respect of the Henry Brown Legacy.

PRESENTS TO THE LIBRARY

The presents received since the last Meeting were laid on the table and the thanks of the Members returned for the same:—

W. J. Green, B.Sc., M.R.I.—Collected notes on the magic mirror of Japan, by C. H. Montgomery. 1947.

Captain H. L. Hitchins, C.B.E., M.R.I.—(1) On the undulatory theory of optics, by G. B. Airy. 1866. (2) Theory of the deviations of the magnetic compass, by G. N. Harvey. 1948.

Perkin Centenary Celebrations Committee—Perkin centenary, London; 100 years of synthetic dyestuffs. 1958.

GENERAL MONTHLY MEETING

Monday, 1 June 1959

THE RIGHT HON. LORD BRABAZON OF TARA, P.C., G.B.E., M.C.
President, in the Chair

The Hon. Eleanor Plumer
Thomas H. Osgood
Miss M. J. Scott

were elected Members of the Royal Institution.

MEMBERS DECEASED

The Secretary announced the decease of the following Members:—

W. G. Gledhill
General Sir Ernest Makins

ASSOCIATE SUBSCRIBER

The Chairman reported that the Managers had elected the following Associate Subscriber:—

W. J. J. Sklodowski

CORPORATE SUBSCRIBER

The Chairman reported that the Managers had elected the following Corporate Subscriber:—

Steel Company of Wales, Ltd.

INVESTMENTS POOL

It was resolved that the Provisions of the Charter granted by Her Majesty Queen Elizabeth the Second on 14 November 1958 relating to the formation of a combined Pool of investments and the Scheme approved and established by Order of the Board of Charity Commissioners for England and Wales dated 26 May 1959 be now put into effect.

PRESENTS TO THE LIBRARY

The presents received since the last Meeting were laid on the table and the thanks of the Members returned for the same:—

Commonwealth Institute—Nuclear explosions and their effects, 2nd ed. 1952.
Institution of Electrical Engineers—Proceedings of the International Conference of Theoretical Physics, Tokyo 1953.
The Librarian, United States Information Service—Scientific, medical and technical books published in thd U.S.A., edited by R. R. Hawkins. 2nd ed. 1958.
Jean Timmermans (through Sir Lawrence Bragg)—Physico-chemical constants of binary systems in concentrated solutions, by Jean Timmermans. Vol. 1. 1959.
Westminster College (through Mr. E. Ironmonger)—14 scientific works.

GENERAL MONTHLY MEETING

Monday, 6 July 1959

THE RIGHT HON. LORD BRABAZON OF TARA, P.C., G.B.E., M.C.
President, in the Chair

The Right Hon. Lord Cohen of Birkenhead
W. S. Eastwood
J. M. Glaisyer
L. Bentley Jones
S. Stein
Miss L. K. Howard Webb
J. F. Whatham

were elected Members of the Royal Institution.

MEMBER DECEASED

The Secretary announced the decease of the following Member:—

Mrs. Isabelle M. Homan

CORPORATE SUBSCRIBERS

The Chairman reported that the Managers had elected the following Corporate Subscribers:—

British Electrical & Allied Manufacturers Assocn. Inc.
B.S.A. Company, Ltd.
Drummonds Branch Royal Bank of Scotland
Skyways, Ltd.
Spillers, Ltd.

DONATIONS

The Chairman reported that the following donations had been received:—

Isaac Wolfson Foundation	£2000
Merchant Taylors' Company	£105

PROPOSED ALTERATIONS TO THE BYE-LAWS

The Chairman gave notice of a proposal to amend Chapter II Article 6 of the Bye-Laws regarding Members' annual payments. The amendment would reduce Members' admission fees to three guineas and raise the annual payment to seven guineas. The Life Composition Fees would be altered accordingly.

PRESENTS TO THE LIBRARY

The presents received since the last Meeting were laid on the table and the thanks of the Members returned for the same:—

Walter Gasson, M.R.I.—Science and thought in the fifteenth century, by Lynn Thorndike. 1929.

Raymond Russell, F.S.A., M.R.I.—The harpsichord and clavichord, by Raymond Russell. 1959.

GENERAL MONTHLY MEETING

Monday, 5 October 1959

THE RIGHT HON. LORD BRABAZON OF TARA, P.C., G.B.E., M.C.

President, in the Chair

G. R. Taylor

was elected a Member of the Royal Institution.

MEMBERS DECEASED

The Secretary announced the decease of the following:—

Hugo Rudolph Kruyt, *Honorary Member*
Sir Alfred Egerton
D. J. Fyffe
L. Bentley Jones
Sir Robert Arthur Young

SIR ALFRED EGERTON

Lord Brabazon spoke of the death of Sir Alfred Egerton who had died very suddenly in the South of France. He referred to Sir Alfred's greatness as a scientist and to the extreme kindness and gentleness of his nature, he was an inspiration to all who came in contact with him. Lord Brabazon went on to say how greatly Sir Alfred would be missed by his friends in the Royal Institution to which he, in his turn, had been very attached.

ASSOCIATE SUBSCRIBER

The Chairman reported that the Managers had elected the following Associate Subscriber:—

Austin B. Stokoe

CORPORATE SUBSCRIBERS

The Chairman reported that the Managers had elected the following Corporate Subscribers:—

Bowater Paper Corporation, Ltd.
Chloride Electrical Storage Co., Ltd.
Gallaher, Ltd.

LIBRARY SUBSCRIBERS

The Chairman reported that the Managers had elected the following Library Subscribers:—

Miss Mary T. Cordon
E. Lederer

DONATIONS

The Chairman reported that the following donations had been received:—

Associated Electrical Industries, Ltd.	£210	0	0
Babcock & Wilcox, Ltd.	£105	0	0
Drapers' Company	£50	0	0
Evershed & Vignols, Ltd.	£25	0	0
Guild of Air Pilots and Air Navigators	£3	3	0
Merchant Taylors' Company	£105	0	0

PROPOSED ALTERATIONS TO THE BYE-LAWS

The proposed alterations regarding Members' annual payments which had been approved at the previous meeting, were carried unanimously.

PRESENTS TO THE LIBRARY

The presents received since the last Meeting were laid on the table and the thanks of the Members returned for the same:—

British Petroleum Research Centre—Themodynamic properties of methane, by H. E. Tester. 1959.

C. M. Cade, M.R.I.—(1) Infra-red navigational aids, by C.M. Cade. 1959. (2) Use of radio sextants in automatic navigation systems. 1959.

Chemical Society—(1) Abstracts of lectures delivered at the R.I. by William Odling. 1874. (2) The organisation of knowledge and the system of the sciences, by H. E. Bliss. 1929.

W. A. Dickie, B.Sc., M.R.I.—Solid state for engineers, by M. J. Sinnott. 1958.

Institution of Electrical Engineers—Lessons in seismic computing, by M. M. Slotnick. 1959.

National Book League—5 German scientific works.

GENERAL MONTHLY MEETING

Monday 2 November 1959

PROFESSOR L. A. JORDAN, C.B.E., D.Sc.
Vice-President, in the Chair

R. A. Chisholm
Miss Barbara Harrison
A. M. Lea
Peter Lindsay
Colonel Sir Stuart S. Mallinson
Thomas Nicklin
G. R. Noakes
Adrian Stephens
Anthony Wild

were elected Members of the Royal Institution.

MEMBERS DECEASED

The Secretary's Deputy announced the decease of the following:—

T. E. Goldup
N. S. Macqueen
Mrs. F. Mathias

CORPORATE SUBSCRIBER

The Chairman announced that the Managers had elected the following:—

British Thomson-Houston Co., Ltd.

PROPOSED ALTERATIONS TO THE BYE-LAWS

The proposed alterations regarding Members' annual payments, which had been approved at the previous meeting, were duly confimed.

PRESENTS TO THE LIBRARY

The presents received since the last Meeting were laid on the table and the thanks of the Members returned for the same:—

International Union of Crystallography—International tables for X-ray crystallography. Vol. 2. 1959.
Viscount Samuel—In search of reality, by Viscount Samuel. 1958.

GENERAL MONTHLY MEETING

Monday, 7 December 1959

THE RIGHT HON. LORD BRABAZON OF TARA, P.C., G.B.E., M.C.
President, in the Chair

W. Cochrane
Lady Egerton
Miss E. Hurtley
G. A. Leach
T. N. Morgan
Miss C. G. Northcott

were elected Members of the Royal Institution.

ASSOCIATE SUBSCRIBERS

The Chairman reported that the Managers had elected the following Associate Subscribers:—

Miss Brenda M. Field
Miss Philippa M. Harris
A. H. Milton
Miss Joan I. Murphy
Miss E. A. W. Oakley
O. Rudwick
B. W. Viney

CORPORATE SUBSCRIBERS

The Chairman reported that the Managers had elected the following Corporate Subscribers:—

Metropolitan-Vickers Electrical Co., Ltd.
M. K. Electric, Ltd.

PRESENTS TO THE LIBRARY

The presents received since the last Meeting were laid on the table and the thanks of the Members returned for the same:—

W. A. Dickie, B.Sc., M.R.I.—(1) Artificial fibres, by R. W. Mocrieff, 1950. (2) Physical chemistry of dyeing, by T. Vickerstaff. 1950.
Librarian, University of London Institute of Education—5 scientific works.
Librarian, Ministry of Supply—Science today. Vols. 3-9. 1948-51.
E. Nightingale, M.Sc., M.R.I.—Higher physics, by E. Nightingale. 1959.
Frank Rumford—Chemical engineering operations, by Frank Rumford. 2nd ed. 1957.

SOME PRINCIPLES OF CLOCK AND WATCH DESIGN

By SIR HAROLD SPENCER JONES, K.B.E., M.A., Sc.D., F.R.S.
Professor of Astronomy and Secretary of the Royal Institution

Weekly Evening Meeting, Wednesday 27th May, 1959

W. E. Schall, B.Sc., F.Inst.P.
Treasurer and Vice-President, in the Chair

THE rotation of the earth provides us with our fundamental unit of time—the day. For convenience in our daily life, this unit is subdivided into hours, minutes and seconds. The function of a clock is to indicate the time that has elapsed since the preceding midnight or noon.

Many different devices have been used in the past to mark the passage of time and therefore to serve as clocks. Amongst them, the regular burning of a candle or oil lamp, or the regular flow of water or sand through a small orifice. Before the invention of mechanical clocks, sundials were used by day and nocturnals by night, when the sky was not cloudy. They continued to be used for some considerable time after the invention of mechanical clocks, for the timekeeping of the early mechanical clocks was very poor and the sundial or nocturnal provided the most convenient, and indeed the only method, of checking the time given by them.

A mechanical clock depends upon the use of some form of cyclic mechanical motion that repeats itself over and over again. To provide reasonably satisfactory timekeeping, a mechanical clock must meet three requirements:

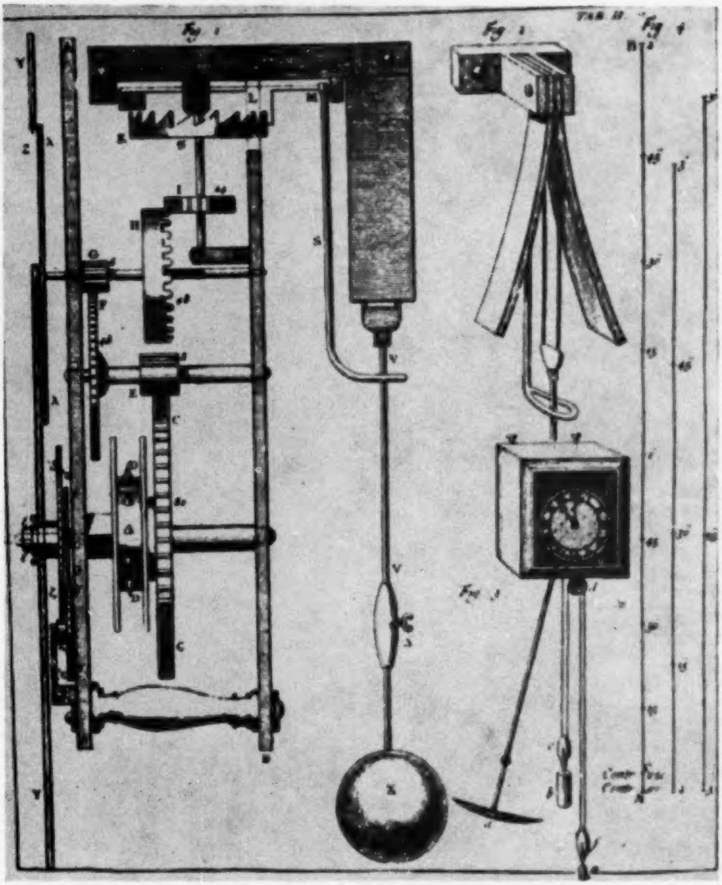
1. It must embody a mechanism that repeats itself regularly, such, for instance, as the swinging of a pendulum.
2. A means must be provided of maintaining this mechanism in action. In other words, energy must be supplied. A swinging pendulum would soon come to rest if it were not continually impulsed.
3. Some form of counting mechanism, which can count up the recurrences and indicate the number in some way, as for instance by a hand or hands moving over a graduated dial.

The earliest mechanical timekeepers employed a pivoted beam,

which was pushed first in one direction and then in the opposite direction by means of a toothed wheel driven by a weight. The two arms of the beam carried weights or riders whose positions along the arm could be adjusted, thereby altering the moment of inertia and consequently the rate of swing of the beam. The rate of the clock could thereby be altered but, since the beam had no natural period of swing, the timekeeping was far from good; it depended upon the precision of the working parts and the accuracy of workmanship. The early clocks were made of iron, usually by blacksmiths, were generally rather large and clumsy, and there was no precision in the working parts. Brass came into use about the end of the 16th century and made possible the construction of smaller and less inaccurate clocks.

In 1581 Galileo, from observing the swing of a lamp suspended in the Cathedral of Pisa, made the epoch-making discovery that the time of swing of a pendulum was independent of the amplitude of the swing. In other words, a pendulum swinging under the influence of gravity has a natural period of swing; it has the property of isochronism. The period is determined by the length of the pendulum—the distance between its point of suspension and the centre of gravity of the bob—and is independent of the weight of the bob. A four-fold increase in the length of the pendulum doubles the time of swing.

It was a natural development to use the pendulum for recording intervals of time. In its first applications, the pendulum was set swinging, the vibrations were counted one by one, and the swing was maintained by hand as required. This was, of course, extremely laborious and not very practical. Many persons were stimulated to attempt to apply the important isochronous property of the pendulum to the design of a pendulum-controlled clock. Amongst them was the great Danish astronomer, Tycho Brahe, who spent much thought and effort in the attempt to design and construct a clock which would be sufficiently accurate for use in his astronomical observations. The problem of finding a satisfactory method of determining the longitude at sea was then demanding a solution. Galileo himself in March 1636 suggested to the States-General of Holland the construction of a mechanism for this purpose. After explaining his proposal he added:



Huygens' Standard Clock. From "*Horologium Oscillatorium*"

PLATE I

"It would be a waste of time to occupy Your Lordships' attention any longer with the details. You can command artists of the utmost skill in the manufacture of clocks and other excellent mechanisms. They have only to know that the pendulum gives vibrations of exactly equal duration, whether the arc be great or small, in order to devise methods of construction of greater precision than any that I could devise."

The scheme was not found to be practical and, after much negotiation, was abandoned. Galileo died on 8 January, 1642.

The credit for being the first successfully to apply the pendulum to control a mechanism for recording the time is usually given to the celebrated Dutch mathematician, Christiaan Huygens, who in 1657 submitted a pendulum clock to the States-General through Samuel Coster, a skilled clockmaker at the Hague, to whom he had assigned his rights in the invention. The States-General granted on June 16, 1657, a patent for 21 years to Coster. The clock, as designed by Huygens, embodied a verge escapement with a horizontal wheel. A crutch was attached to the end of the verge; the pendulum was suspended by a double thread from a bracket and passed through the fork of the crutch.

The following year Huygens, in a small Latin treatise entitled "Horologium", published a modified design with essentially the same escapement but the crown wheel was in a vertical position; the top of the verge was provided with a pinion which engaged in a contrate wheel, toothed for only half its circumference, to which the crutch was attached. The advantage of this arrangement was that the arc of vibration of the pendulum was much reduced and was in consequence less subject to irregularity.

In December 1659 Huygens discovered that a pendulum is not strictly isochronous but has what is termed 'circular error': in other words, the time of swing depends to a small extent upon the arc of vibration. He found that if the pendulum described a cycloidal instead of a circular curve, the time of swing was then the same whatever the arc of vibration. In his great work, "De Horologio Oscillatorio", published in 1673, he proved this mathematically. In his later clocks he made the flexible suspension of the pendulum swing against cycloidal-shaped brass cheeks, which ensured that the bob moved along a cycloidal curve. Though this was theoretically correct, it proved not to

be satisfactory in practice because of variable friction between the suspension and the cheeks (Plate I).

Great as were the achievements of Huygens, it has since become clear that in the application of a pendulum to control a clock he was forestalled by Galileo. Something of this was known in Huygen's lifetime, though it was not until much later that the full facts became known. When a specimen of Coster's clocks of 1657 and a copy of "Horologium" reached Florence, the disciples of Galileo resented the attempt, as they regarded it, to rob Galileo of the credit of being the first to control clockwork by means of a pendulum, and charged Huygens with plagiarism. An acrimonious disputation followed and continued for many years.

The Minutes of the Accademia del Cimento of August 11, 1662, contain an entry which, after referring to Galileo's simple pendulum kept in motion by hand, states that "for experiments requiring nicer precision it was judged advisable to apply the pendulum to the clock which Galileo, before anyone else, had devised, and his son Vicenzio had put into practice as early as 1649".

In the introduction to "De Horologio Oscillatorio", Huygens strongly repudiated the charge of plagiarism. He said that it was beyond the bounds of credence that so useful an invention could have remained unknown for eight whole years until he published it himself.

Johann Becher in his treatise "De nova temporis dimitiendi ratione Theoria", dedicated to the Royal Society in 1680, stated that the Count Lorenzo, Resident of the Grand Duke of Tuscany at the Court of the Emperor, had told him the whole history of the pendulum clocks, and denied that Huygens was the author of them. He further declared that the clockmaker to the Grand Duke, Treffler by name, had told him that he had made the first pendulum clock at Florence by command of the Grand Duke, from the directions of his mathematician, Galileo Galilei, a pattern of which was brought into Holland.

The story of the way in which Galileo's invention eventually became known is a curious and romantic one.

In 1649, Galileo's son, Vicenzio, died. His widow died in 1669, appointing as her executor Vicenzio Viviani, the man at whose

suggestion the Accademia del Cimento, a society of men of science, similar to our Royal Society, had been founded. In the inventory of her effects, which still exists, appears an entry "An iron clock, unfinished, with pendulum, the first invention of Galileo".

Viviani died in 1703 at the age of 81. He possessed all Galileo's unpublished manuscripts and much of his scientific correspondence; on his death these passed to his nephew and heir, who apparently knew nothing of their value nor possibly even of their existence. After the death of this nephew, his heirs sold a mass of papers, which had been hidden at the bottom of a corn-bin, to a pork butcher in Florence for use as wrapping. By good fortune one of the parcels came into the hands of Clemente de Nelli, a Senator of Florence, who recognised a letter of Galileo, followed up the trail and recovered all that remained of the papers. These he used in writing the life of Galileo, which shortly after his death was printed in 1793 in Florence, but disguised under the imprint of Lausanne. It was not, however, until 1811 that the work was published. Then it was that a letter dated August 20, 1659, that Viviani had written to Prince Leopold was first made known to the world. Leopold dei Medici was the brother of the then reigning Duke Ferdinand II of Tuscany, who had been a disciple and great admirer of Galileo, and president of the Accademia del Cimento on its foundation.

In this important and interesting letter, Viviani referred to Galileo's discovery of the isochronism of the pendulum and of his negotiations, first with Spain and subsequently with the States-General of Holland, for the adoption of his proposals for the application of the pendulum to the measurement of longitudes. The letter continued as follows:

> "One day in the year 1641, whilst I was living with him in his country house at Arcetri, I recollect that it came into his mind that the pendulum could be adapted to clocks driven by weight or spring, in the hope that the perfect natural quality of its motion would correct the imperfections of mechanical construction. But, being deprived of sight and unable himself to execute the plans and models that would be required to ascertain which would be best adapted for carrying out this project, he communicated his idea to his son Vicenzio,

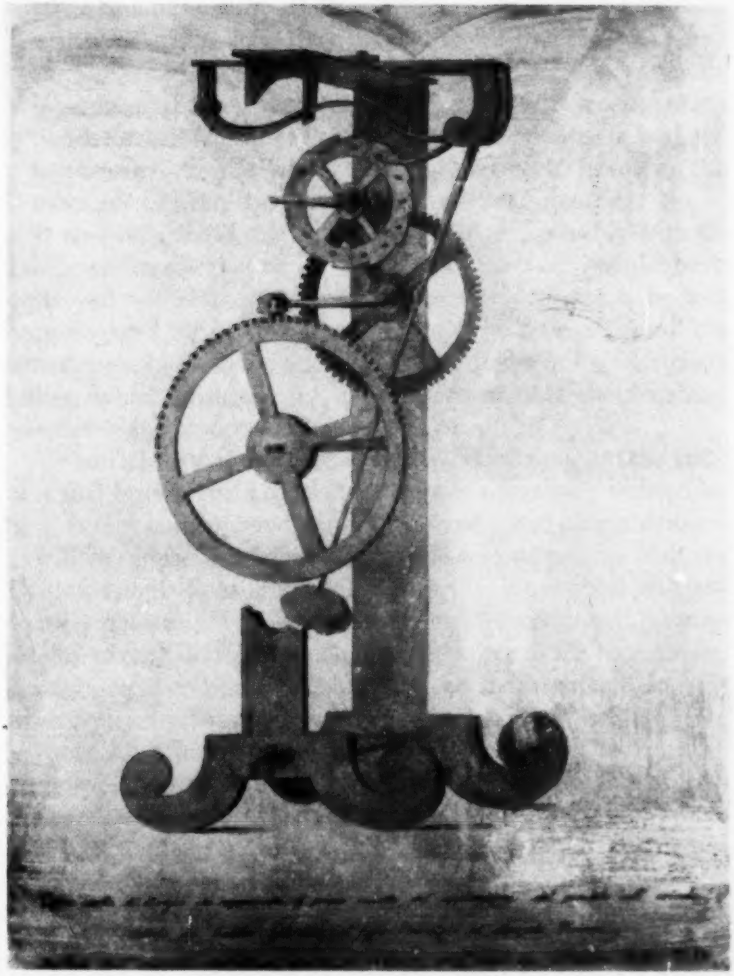
who had come out one day from Florence to Arcetri. They had several discussions on the subject, with the result that they fixed upon the method, of which the accompanying drawing is a copy (PlateII), and they decided to proceed at once with its execution, in order to determine what were the difficulties, which, as a rule, in the construction of machines, a theoretical design does not reveal. But Vicenzio, being desirous to construct the instrument with his own hands, for fear lest the artificers who might be employed should divulge it before it had been presented to the Grand Duke and to the States-General of Holland for the measurement of longitudes, kept putting off its execution, and a few months later Galileo, the author of this admirable invention, fell ill, and died on January 8, 1642. As a consequence, Vicenzio's enthusiasm cooled down, so that it was not until the month of April 1649 that he took in hand the manufacture of the accompanying design of the clock, made in accordance with the conception which his father had already imparted to him in my presence."

After a technical description of the mechanism, the letter states that Vicenzio engaged a young blacksmith, Domenico Balestri, who had some experience in the construction of large wall clocks and was still living. He caused him to make the iron framework, the wheels and their arbors and pinions, but without cutting them, and he executed the rest of the work with his own hands. "Vicenzio gave me more than once a demonstration of the connexion of the movement which in this way he had consummated as between the weight and the pendulum, in view of my acquaintance with the invention and of my having urged him to execute it."

The account then mentions that when Vicenzio and Viviani examined the invention, certain difficulties presented themselves, which Vicenzio hoped to overcome; he also thought that he could adapt the pendulum to the clock in another way and with other inventions; but that, having gone so far, he desired to complete it according to the actual design, by adding dials for the hours and minutes as well; whereupon he set to work to cut the other toothed wheels.

Viviani then proceeds as follows:

"But, whilst engaged in this unwonted task, he was over-



Copy of drawing representing Galileo's idea for applying the pendulum to clock mechanism. (*Crown Copyright, Science Museum, London*).

PLATE II

taken by a most acute attack of fever, and was obliged to leave it unfinished; and on the 21st day of his illness, that is, on May 16, 1649, all the most accurate clocks, together with this most accurate time measurer, were by him destroyed and stopped for ever; whilst he (as it pleases me to believe) passed on, to measure, in the enjoyment of the Divine Essence, the moments of Eternity, that pass all understanding."

It was very tragic that, in a fit of delirium, possibly with an overpowering disgust of all clockwork, Vicenzio should have destroyed with his own hands all the work on which he had been engaged for several years, not only the timekeepers of his own design, but also the one made to the design of his illustrious father, which required for its completion only the finishing touches of the motion work.

Viviani's letter was not in his own handwritting, but the copy of it that has survived contains corrections that were written by him. It may be wondered why it remained for so long unknown. It will be remembered that Galileo had serious trouble with the Roman Inquisition, and in Tuscany the Inquisition was extremely powerful. Viviani may well have feared that, if his possession of the Galileo papers had been known to the Inquisition, it might have compromised him or even that the papers might have been seized and destroyed.

Professor Alberi, who was the Editor of Galileo's works in 16 volumes (1842–56), on making a final search through Galileo's papers discovered the original drawing of the mechanism, which had been folded up amongst other scraps of paper, and it was reproduced in Vol. XVI of his edition of the works of Galileo.

The matter can be carried a little further. Ismaël Boulliau, the author of "Astronomia philolaica", 1645, who was a close friend and correspondent of Huygens, sent to Prince Leopold in 1658 a copy of Huygens' "Horologium" and in February 1659 he wrote that he was sending the Prince a clock. In reply the Prince admitted that Huygens' clock was certainly a beautiful invention but that Galileo must not be robbed of his glory. He went on to state that he had discovered a model already made by Vicenzio Galileo, and that three years ago (i.e. in 1656) a clock was made from it by an expert. The expert was probably Treffler, whom I have already mentioned.

A further letter from Boulliau to Prince Leopold, dated May 2, 1659, is interesting as showing that Huygens did not at that time claim undisputed authority. Huygens had told him, with regard to the use of the pendulum for governing clockwork, that he did not know who was its first author, and he would take care not to arrogate it to himself only and thus alone claim the glory. But he thought he was entitled to fame for having hit upon the same conception as Galileo. Boulliau replied to Huygens that he (Huygens) was far too honourable to rob another of his fame. Huygens in reply said that, on the assurance of so great a prince, one must believe that Galileo had had the idea before him: if he knew the Prince better he would ask for a drawing. On Leopold being informed, he wrote to Boulliau on August 21, 1659, that he was sending the design of Galileo's clock, "drawn with the same roughness as is the model made from it, which is now in my room." He adds, "You may send it to Huygens, and perhaps next week I shall send you the history of the discovery of the pendulum. I shall also have a drawing made showing how we have fitted the pendulum to our clocks, particularly to a very large striking-clock in the Piazza of our Palace."

This drawing is now in the possession of the University of Leiden. It bears a Latin inscription in Huygens' writing, the translation of which is: "Sent by His Serene Highness Prince Leopold to Boulliau, by him to me: Received January 15, 1660, when the description of my own clock had been published in 1658." The drawing has also a note in French in Boulliau's hand: "Horloge commencé par Galileo Galilei avec un pendule."

While the priority of Galileo in adapting a pendulum to control a clock must be admitted, it seems only just to acquit Huygens of any charge of plagiarism. Nevertheless he seems to have resented the fact that he had been anticipated in the invention by Galileo. In his Preface to his "Horologium Oscillatorium", 1673, he wrote:

"As to those who endeavour to ascribe priority to Galileo, if they say that he had attempted though not completed the invention, they would seem to detract more from his merit than from mine, inasmuch as I prosecuted the same investigation with better success than he. But when, as a certain learned man has recently alleged, they maintain that the in-

vention was brought to completion either by Galileo himself, or by his son, actually exhibiting clocks of this kind, I know not how they can hope to gain credence, seeing that it is scarcely likely that so great an invention could remain unknown for eight whole years, until it had been brought to light by me. But, if they say that it was intentionally kept secret, they are asserting precisely what anyone can pretend, who seeks to arrogate to himself the priority of an invention."

Viviani himself, upon receipt of a copy of Huygens' book, wrote a letter to Count Lorenzo Magalotti, the former secretary of the Accademia del Cimento, on July 24, 1673, in which he said:

"I fail to understand why Signor Ugenio should exhibit so much passion and be so jealous of the priority in this matter, seeing that anyone who is cognizant of the sublimity of his inventive genius will always and readily believe that he may yet very well have invented subsequently and of his own initiative and information, such application of the pendulum; in which case it is very certain that he is deserving of the same praise as though no one else had ever thought of it before."

There is no question that Galileo's invention is far more original, subtle and ingenious than Huygens'. Whereas Huygens used the pendulum to control the irregular action of the old verge escapement, which had been in use for more than three centuries, Galileo designed an escapement that embodied entirely new ideas, combining it with a detent—a complete break from long-established tradition and usage. It is surprising that Huygens failed completely to comprehend the ingenuity of Galileo's mechanism. On receipt of the copy of Galileo's drawing he wrote to Boulliau in Paris, on January 22, 1660:

"You have given me great pleasure by sending me the drawing of the clock commenced by Galileo. I see that it has a pendulum, just as mine has, but not applied in the same manner, because, in the first place, he has substituted a much more complicated invention, instead of making use of the wheel, which is termed the crown-wheel. In the second place, he has not suspended the pendulum by a thread or narrow band, so that the whole of its weight rests on the spindle upon which it moves; this doubtless is the principal reason why his method was not much of a success; for I know by

experiment that its motion becomes far more troublesome, and the clock is liable to stop. Although, then, Galileo had the same idea as myself as regards the use of the pendulum, that is rather in my favour than the contrary; because I have effected that which he did not succeed in accomplishing; and in any case I never had from him nor from anyone whomsoever any hint or suggestion as to this invention. If anyone should ever prove the contrary, let him brand me as a plagiarist, thief or whatever else he may fancy."

The next important development in horology was the invention of the anchor or recoil escapement, which has been widely used in long-case or grandfather clocks even up to the present day. Here again, there has been a long-standing controversy as to whom the credit for the invention should be given. The anchor escapement interferes much less with the free swing of the pendulum than the old verge escapement or even the escapement invented by Galileo, and permits of a smaller arc of vibration. It is strange that the origin of so important an invention, which has been so widely used in domestic pendulum clocks, should be shrouded in obscurity. Claims have been made for William Clement, a London clockmaker, and also for the ingenious and disputatious Robert Hooke. The Science Museum possesses a turret clock with an anchor escapement and bearing the inscription, "Guglielmus Clement Londini fecit 1671". This clock was made for King's College, Cambridge, where it remained until 1817, when it was transferred to St. Giles' Church, Cambridge. It was presented to the Science Museum in 1926. I believe this to be the earliest clock with an anchor escapement whose maker and date are known with certainty.

John Smith, the author of a book entitled "Horological Disquisitions", published in 1694, referred to Huygens' invention of the pendulum-controlled clock and wrote thus:

"From Holland, the fame of this Invention soon past over into England, where several eminent and ingenious Workmen applyed themselves to rectify some Defect which as yet was found therein; among which that eminent and well-known Artist, Mr. William Clement, had at last the good Fortune to give it the finishing Stroke, he being indeed the real Contriver of that curious long kind of Pendulum, which is at this Day so

universally in use among us. This Invention that exceeds all others yet known, as to the exactness and steadiness of its Motion, which proceeds from two properties, peculiar to this Pendulum: the one is the weightiness of its Bob, and the other the little compass in which it plays: the first of these makes it less apt to be commanded by those accidental differences of strength that may sometimes happen in the Draught of the Wheels, and the other renders the vibrations more equal and exact, as not being capable of altering so much in the distance of its swings, as these other kinds of Pendulums are, who fetch a larger, and, by consequence, a less constant Compass."

The invention is thus attributed by Smith to Clement in very definite terms.

William Derham in 1696 published a book entitled, "The Artificial Clockmaker". In this book he gives the following information:

"After Mr. Huygens had thus invented these Pendulum Watches, and caused several to be made in Holland, Mr. Fromantil, a Dutch clockmaker, came over into England, and made the first that ever were made here: which was about the year 1662.

"For several years this way of M. Zulichem was the only method, viz. Crown-wheel pendulums, to play between two cycloidal cheeks, etc. But afterwards Mr. W. Clement, a London clockmaker, contrived them (so Mr. Smith saith) to go with less weight, an heavier Ball (if you please) and to vibrate but a small compass, which is now the universal method of the Royal Pendulums.

"But Dr. Hook denies Clement to have invented this; and says that it was his Invention, and that he caused a piece of this nature to be made, which he showed before the Royal Society, soon after the Fire of London."

The quotations I have given provide the only available evidence on this matter. It is surprising that nothing more definite is known about an invention of such importance in horology. The anchor escapement was never patented. There is in fact no record in the Patent Office of any horological patent being granted between March 1665 and March 1694, possibly because of the entire dislocation of business caused by the Great Fire, for this

was a period in which our great clockmakers were particularly fertile in invention.

It should be noted that Derham mentioned Clement first and referred to Smith's very definite attribution of the invention to Clement before stating that Hooke denied that Clement had invented it. Smith's statement about Clement, "he being indeed the real contriver", suggests that in 1694 there may already have been a dispute about the inventor of the anchor escapement.

Hooke's assertion that he invented the escapement and caused a clock fitted with it to be shown before the Royal Society is not supported by the minute books of the Society. These books contain a number of references to Hooke in connection with clocks, watches and pendulums. Many of them refer to his circular pendulum, but none of them seem to relate in any way to the anchor escapement.

Hooke died in 1702. Almost immediately Richard Waller sat down to write the Posthumous Works of Robert Hooke, which were published in 1705. Yet he made no mention of the anchor escapement nor even of Hooke's claim to have invented it, as recorded by Derham. Furthermore Derham, who was a great admirer of Hooke, made no reference to the anchor escapement in his work entitled "Philosophical Experiments and Observations of the late Eminent Dr. Robert Hooke, F.R.S." which was published in 1726. It seems incredible that an invention which had become so widely used by clockmakers would not have been mentioned both by Waller and Derham if Hooke had actually been the inventor.

In the anchor escapement, the teeth of the escape wheel fall upon the inclined surfaces of the anchor pallets themselves and are first driven backwards and then run down the pallets to escape, giving impulse as they do so. There is consequently some interference with the free swinging of the pendulum which recoils slightly, so that the escapement is often called the recoil escapement. It was improved by George Graham about 1715 in his invention of the so-called "dead-beat" escapement, in which the recoil is avoided. The surface of the pallet slides along the tooth of the escape wheel and the impulse is given to the pendulum near its zero position. This escapement permits of much greater accuracy in timekeeping and has been much used in clocks of

high quality such as the regulator clocks that were for long used as standard clocks in astronomical observatories.

The invention of portable clocks and watches was first rendered possible when a spring was employed to supply the driving power of the mechanism. The first spring-driven clocks were made in the latter part of the 15th century. True watches, timepieces small enough to be carried on the person, followed very early in the 16th century. They employed a verge escapement, a wheel or dumb-bell shaped bar replacing the foliot balance; the wheel or bar was pushed first one way and then the other by means of a crown wheel and verge escapement. As the balance had no timekeeping property of its own, these early watches were very bad timekeepers.

The invention of the balance spring, about 1670, brought about an improvement in the timekeeping of watches comparable with the improvement in the timekeeping of clocks that resulted from the employment of the pendulum. The question of who was the first to control the motion of the balance wheel by means of a spiral spring has been another matter of much controversy. Claims have been made for both Hooke and Huygens.

Hooke turned his attention to the improvement of portable timekeepers about 1658. In his Cutlerian lectures in 1664 he dealt with the application of springs to the balance of a watch in order to render its vibrations more uniform. He said that he knew 20 different ways of applying them, some of which he illustrated by models. He admitted that he kept the best methods secret in order to use them for his own advantage. It is not known whether the use of a spiral spring was amongst the methods that were kept secret.

The principle of the balance spring was expressed by Hooke in a Latin anagram, the solution of which is "Ut tensio, sic vis" —as the tension is, so is the force. The force exerted by any spring is directly proportional to the extent to which it is tensioned. It follows that the balance spring is isochronous, like a pendulum. A balance that moves with perfect freedom except for the control of the spring will always perform one vibration in an interval of time, whether the arc is large or small. The credit for realising this must certainly be given to Hooke.

William Derham gave an account, in his "Artificial Clock-

maker", of the invention of those pocket watches, commonly called pendulum watches. He stated that:

"The first Inventor was that ingenious and learned member of our Royal Society, Dr. Hook: who contrived various ways of Regulation . . . . . But the Invention which best answered expectation, was at first, with two balances: of which I have seen two sorts . . . . . One way was without spiral springs, the other with . . . . And the excellency of the latter is, that no jirk, or the most confused shake, can in the least alter its Vibrations. (This, he says, is not the case with a single balance). But notwithstanding this inconvenience, yet the watch with one ballance and one Spring (which was also Dr. Hook's Invention) prevailed, and grew common, being now the universal Mode: but of the other very few were ever made . . . . The reason hereof, I judge, was the great trouble and vast niceness required in it . . . .

"The time of these Inventions was about the year 1658, as appears (among other evidence) from this inscription, upon one of the aforesaid double Ballance-Watches, presented to K. Charles II, viz. Rober. Hook inven. 1658. T. Tompion fecit 1675. This watch was wonderfully approved by the King; and so the Invention grew into reputation, and was much talked of at home, and abroad. Particularly its fame flew into France, from whence the Dauphine sent for two; which that eminent artist, Mr. Tompion, made for him."

The engraving on the watch is not perhaps conclusive proof that by 1658 Hooke had used spiral springs, though he must have done so before Tompion constructed the watch for Charles II in 1675, and probably some years before.

In 1675 Huygens, who was then resident in Paris and in receipt of a pension from Louis XIV, applied to the Minister Colbert for a "privilege" for his spiral spring balance, which was quickly granted. Protests were made when this privilege was granted, in consequence of which Huygens took no further action. But he wrote to Oldenburg, the Secretary of the Royal Society, offering to him or to the Society all his interest in the invention, if it was thought that a patent in England would have any value. This letter was read to the Society on the 28th February, 1675, whereupon Hooke said that "divers years ago he had had such an in-

vention, and that actually watches had been made according to the same, for which he appealed to the Journal books and to several members of it."

Hooke was extremely indignant at being robbed, as he thought, of the credit of the priority in the invention and he accused Oldenburg of having revealed his secret to Huygens. Oldenburg wrote to Huygens informing him of Hooke's accusations. He

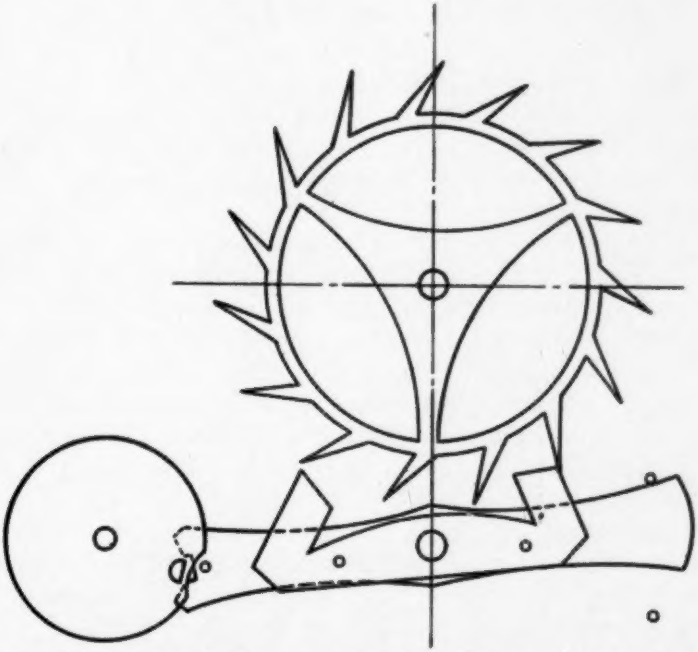


FIG. 1. Diagram of English lever escapement. (*Crown Copyright, Science Museum, London*).

said in this letter that such accusations were as atrocious as false and mentioned that he had never communicated anything to him (Huygens) about this invention, nor of any other until after Huygens had revealed his own to the Society. He begged Huygens to tell the whole truth as fully as he possibly could.

In response to this appeal, Huygens wrote to Lord Brouncker, the President of the Royal Society, stating that Hooke's accusations were false. He said of Hooke that "it is his customary vanity

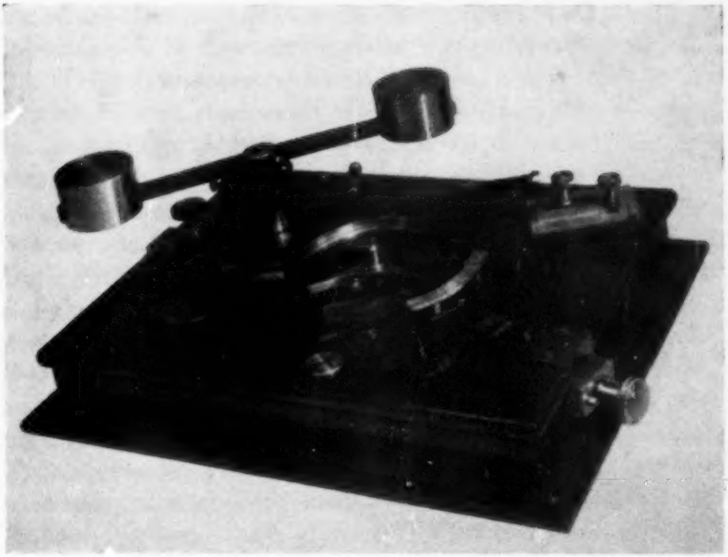
to claim the invention of everything". Lord Brouncker, in his reply to Huygens on November 8, 1675, said, "I am confident of the innocency of Mr. Oldenburg in all that Mr. Hook thought fit to charge him with."

William Derham, in his "Artificial Clockmaker", referred to Huygens' invention as follows:

> "After the Inventions of Dr. Hook . . . . Mr. Hugen's watch with a Spiral Spring came abroad and made a great noise in England, as if the Longitude could now be found . . .
>
> "This watch of Mr. Zulichem's agreed with Dr. Hook's in the application of the Spring to the ballance: only Mr. Zulichem's had a longer spiral spring, and the Pulses and Beats were much slower . . . . . The ballance, instead of turning scarce quite round (as Dr. Hook's) doth turn several rounds every vibration.
>
> "Whether or no that ingenious person doth owe anything herein to our ingenious Dr. Hook, it is however a very pretty and ingenious contrivance; but subject to some defects: viz. when it standeth still, it will not vibrate until it is set on vibrating: which, tho' it be no defect in a Pendulum Clock, may be one in a Pocket Watch, which is exposed to continual jogs. Also, it doth somewhat vary in its vibrations, making sometimes longer, sometimes shorter turns, and so some slower, some quicker vibrations."

It seems that Hooke, over a period of years, had investigated many different ways of using a spring to regulate the motion of the balance of a watch and was probably the first to realise the isochronous property of the spring. Both Hooke and Huygens had independently realised the advantage of making the spring in the form of a spiral. Hooke's method was preferable to Huygens' and, when the use of a balance-spring later became a regular feature of watch mechanisms, it was Hooke's method rather than Huygens' that was used. The priority in the invention should probably be attributed to Hooke but, as he never published a description of it in print, this must remain somewhat doubtful.

The verge escapement was used in the early watches in conjunction with a "fusee". The time of swing of the balance depended upon the driving force exerted by the main-spring. The purpose of the fusee was to obtain a uniform torque as the spring



Large-scale model of chronometer escapement. (*Crown Copyright, Science Museum, London*).

PLATE III

uncoiled. The spiral balance spring improved the timekeeping properties. A further improvement was obtained through the use of the cylinder escapement, invented about 1720 by the famous English clockmaker, George Graham, who is buried in Westminster Abbey. The escape wheel teeth, which are pointed, engage alternately with the outer and inner surface of a highly-polished half cylinder, mounted on the same axis as the balance wheel. The impulse is given by the inclined faces of the teeth of the escape wheel on the edges of this half cylinder as unlocking takes place. With this type of escapement the fusee was no longer necessary and its use was gradually discontinued, thereby enabling watches to be made much thinner.

Many different designs of escapement have been invented and used in watches, some to a much greater extent than others. The detached lever escapement (Fig. 1), the type most commonly used today, was invented about 1754 by the English horologist, Thomas Mudge, though it was little used by him. It has been stated that this escapement was the greatest single improvement, except the balance spring, ever applied to watches. The escape wheel engages alternatively with two pallets mounted on a lever. One end of the lever is notched to engage with a pin carried by a disc or roller mounted on the balance arm. The motion of the lever is limited by two banking pins. The impulse is given by the escape-wheel tooth sliding along the inclined face of the pallet. The important feature of this escapement is that the balance swings freely except when the roller-pin engages with the notch in the lever arm, hence during the greater part of its swing. For this reason the escapement is termed a detached escapement. In modern watches the pallets and the roller pins are jewels, whereby friction is reduced. Despite the great advantages of this type of escapement, it only gradually came into general use.

In marine chronometers, for which a high precision in timekeeping is required, the standard form of escapement is the detached spring-detent escape, invented by the English maker, Thomas Earnshaw about 1782 (Plate III). The escape-wheel teeth are locked by a locking pallet, carried on an arm or detent which is mounted on a spring. Attached to the detent is a fine spring, usually made of gold, which projects slightly beyond the end of the detent. Rollers on the balance arm carry an impulse pal-

let and a discharging pallet. The latter engages with the gold spring. When the balance moves in one direction it pushes this spring away. When moving in the opposite direction, the detent is pushed aside, the locking pallet is freed from the escape-wheel tooth and the escape wheel is given an impulse by the impulse pallet. The impulse is given on alternate vibrations only, the balance swinging freely without interference except at the moment of impulse.

The most famous of all clocks is the Westminster clock, popularly known as Big Ben, whose centenary is being celebrated in a few days' time. The escapement of this clock, known as the double three-legged gravity escapement, was invented by Sir E. Beckett, later Lord Grimthorpe. With most escapements variations in the driving force cause variations in the arc of swing of the pendulum with consequent variations in timekeeping. In a gravity escapement, of which there are several different designs, the wheel train does not drive the pendulum directly but raises a lever or levers which, on their subsequent fall under gravity, give an impulse of constant amount to the pendulum. The arc of swing is then independent of variations in the driving force. The error of Big Ben rarely exceeds one second and is normally less than half a second. The anchor and dead-beat escapements are not very satisfactory for use in large turret clocks, whose hands are exposed to wind and weather, resulting in undesirable variations in the force driving the escape wheel, which is connected through gearing with the hands. Grimthorpe's escapement has consequently become the standard pattern for use in turret clocks.

EXHIBITS IN THE LIBRARY

(*a*) Working models of various escapements and a model of the double three-legged gravity escapement invented in 1854 for the Westminster Clock (Big Ben), lent by the *British Horological Institute*.

(*b*) Models of Graham's dead-beat escapement, and the Duplex and Lever escapements, from the *R.I. Collections*.

(c)Early books on clocks and watches, from the *R.I. Library*.

COLOUR IN INORGANIC CHEMISTRY

By R. S. NYHOLM, D.Sc., F.R.I.C., F.R.S.
Professor of Chemistry, University College, London

Weekly Evening Meeting, Wednesday 10th June, 1959

Sir Harold Spencer Jones, K.B.E., M.A., Sc.D., F.R.S.
Secretary and Vice-President, in the Chair

WHEN describing a chemical substance the first two properties quoted are usually its *form* (i.e. whether gas, liquid or solid) and its *colour*. In general, a reasonable explanation of the former can be given in terms of the inter-ionic, inter-molecular or inter-atomic forces but a satisfactory explanation of the latter has been lacking until fairly recently. In general, it was recognised that *intra*-atomic electronic transitions—as with the rare earth ions—or *inter*-atomic transitions are responsible for colour but the detailed mechanism of these has had to await recent developments in the quantum theory of valency. We shall confine our attention here to the colours of *inorganic* compounds and especially to those substances where the colour arises from intra-atomic electron transitions. A brief discussion only of charge transfer phenomenon will be given.

Since there is no colour without light, we must first say something about white light and its constituents. It is a matter of common knowledge that an incident beam of white light is refracted at the surface of a prism when the latter is placed in a medium of lower refractive index (e.g. glass in air) as shown in Figure 1. In the spectrum which is produced, blue light is bent most and red light least—a factor of importance when considering the effect of particle size upon colour. The individual colours of white light have thus been separated. They may be obtained separately in two other ways—by producing either an *absorption* spectrum or an *emission* spectrum. The former is obtained by passing white light through a suitable coloured translucent material (e.g. a coloured glass slide or a solution in a cell). The transmitted light has had certain colours removed from it; this is the origin of the colour of most chemical substances. The same effect is obtained by reflecting light from the surface of a solid material but the spectrum obtained is less easy to interpret owing to scattering of light and the fact that the absorption is dependent upon

the angle of incidence and the smoothness of the surface. The absorbing power of a translucent solid, liquid or solution is usually given by a curve showing % absorption of the incident light as a function of wavelength of the light used. For solutions, the relationship between the intensity of the incident light (I_o), the transmitted light (I), the thickness of the solution l, the concentration of the dissolved substance (c, in moles/litre) is given by the expression $\log \frac{I_o}{I} = lc\epsilon$ where ϵ is a constant for a particular compound at a particular wavelength. The latter is known as the Molar Extinction Coefficient.

An emission spectrum is obtained by suitably exciting an atom, usually by heat, and electronic transitions occur which

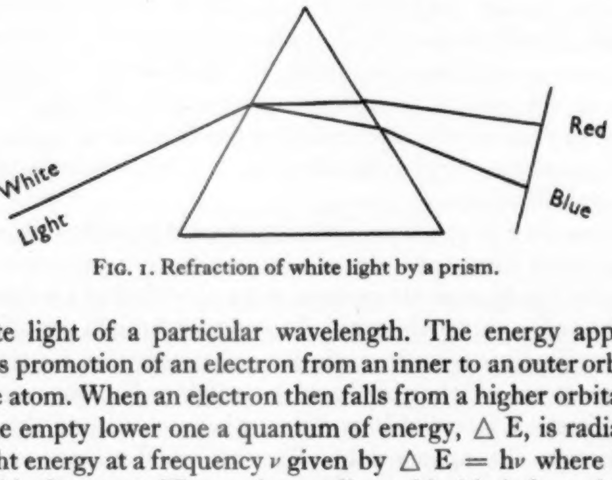


FIG. 1. Refraction of white light by a prism.

radiate light of a particular wavelength. The energy applied causes promotion of an electron from an inner to an outer orbital of the atom. When an electron then falls from a higher orbital to fill the empty lower one a quantum of energy, Δ E, is radiated as light energy at a frequency ν given by $\Delta E = h\nu$ where h is Planck's Constant. Thus, when sodium chloride is heated in a bunsen flame the characteristic yellow colour arising from the D line for sodium (a doublet at 5890 Å) is observed. Similar emission spectra are given by other elements and are the basis for various qualitative tests in chemistry and indeed, for the quantitative estimation of elements in metallurgical analysis. Common elements besides sodium which give rise to characteristic lines in the visible spectrum on thermal excitation include lithium (6708 Å—crimson red); potassium (4044 and 4047—blue and 7699, 7644—red; the latter lines are removed by a blue

	WAVELENGTH in Angstrom Units	ENERGY as Reciprocal cm.	ENERGY as Kilocal./gm. atom	ENERGY as Electron Volts
VIOLET	4,000	25,000	71.5	3.10
BLUE				
	5,000	20,000	57.2	2.48
GREEN				
YELLOW	(5,980	Sodium D	Line)	
ORANGE	6,000	16,667	46.5	2.06
RED	7,000	14,300	41.0	1.77

FIG. 2. The Visible Spectrum

glass filter which is used in analysis to mask the intense yellow colour due to sodium.) Rubidium (4201, 4215—blue violet); caesium (4555, 4593 violet); calcium (6182, 6203—red); strontium (6060—red); barium (5535—green).

TABLE I

COLOURS OF TRANSITION METAL ION HYDRATES IN SOLUTION.

(Together with those of certain preceding and following ions.)

(Sulphates or Perchlorates)

(Usually ions of the type $[M(H_2O)_6]^{n+}$)

Total number of "d" Electrons	Number of Unpaired "d" Electrons	Metal Ion	Colour
0	0	K^+, Ca^{++}, Sc^{3+}	Colourless
1	1	Ti^{3+}	Pink-Violet
2	2	V^{3+}	Green
3	3	Cr^{3+}	Violet
4	4	Cr^{2+}	Blue
5	5	Mn^{2+} Fe^{3+}	VERY pale pink VERY pale violet
6	4	Fe^{2+}	Green
7	3	Co^{2+}	Pink
8	2	Ni^{2+}	Green
9	1	Cu^{2+}	Blue
10	0	Cu^+, Zn^{2+}, Ga^{3+}	Colourless

Emission and absorption spectra are, in a sense, complementary. Thus, an examination of the spectrum of the sun shows that there are certain black lines (Fraunhoffer lines); these appear at precisely the positions where emission spectra for various

atoms are known to occur. Thus, one such black line in the solar spectrum occurs at 5890 Å (a doublet) and this is attributed to absorption, by sodium atoms in the outer region of the sun's atmosphere, of the characteristic wavelength required for excitation.

Light is a form of energy and a particular wavelength can be referred to in several ways, the most convenient being shown in Figure 2. The use of reciprocal cm (cm^{-1}) is convenient since the value employed is then proportional to the energy quantum involved. In addition, the energy can be expressed in terms of kilocalories per gm atom or in terms of electron volts as is shown. The latter is particularly convenient for this discussion. Now a glance at the ionisation potentials for the elements reveals that the smallest of these (3.87 e.v. for caesium) is still larger than the quantum corresponding with violet light (3.10 e.v.). Hence, we conclude that electronic transitions involved in atomic spectra are intra-atomic. The ionisation potentials for the other alkali metals are even higher (Rb, 4.16 e.v.; K, 4.32 e.v.; Na, 5.12 e.v.; and Li, 5.36 e.v.).

We now pass to a consideration of the factual material and will deal mainly with the compounds of metals. Ignoring elements, we can divide metallic compounds into two main groups for our purpose, those which are dilute and those which are concentrated. The former are exemplified by the hydrated salts, e.g. pink $[Co(H_2O)_6]SO_4.H_2O$ and the latter by solid oxides and sulphides, e.g. black NiO and black FeS. The colours of the former are more easily explained and will be discussed first. In Table I are shown the colours of the (hydrated) ions of the metals of the first transition series together with those of certain ions before and after the transition series. A study of this table shows clearly that for ions with closed shell configurations (18 electrons for K^+, Ca^{2+} and Sc^{3+} and 36 electrons for Cu^+, Zn^{2+} and Ga^{3+}) no colour is observed. In all other cases the ions are coloured in aqueous solution; however, the intensity of colour in the cases of Mn^{2+} and Fe^{3+} is much less than that of the others. The significant feature is that these elements have partially filled *d* orbitals, the unusually weak colours of Mn^{2+} and Fe^{3+} arising from half-filled *d* shells. We now consider the location of these *d* electrons inside the atom.

Although the Bohr atom is a convenient one for some purposes it does not give us a true picture of the actual spacial disposition of an electron (orbital); however, the shape of orbitals does emerge from quantum mechanics. These five possible *d* orbitals are shown in Figure 3, referred to *x*, *y* and *z* axes. If we consider a free Ti^{3+} ion with one *d* electron, then this electron does not distinguish between the five possible *d* orbitals since these are

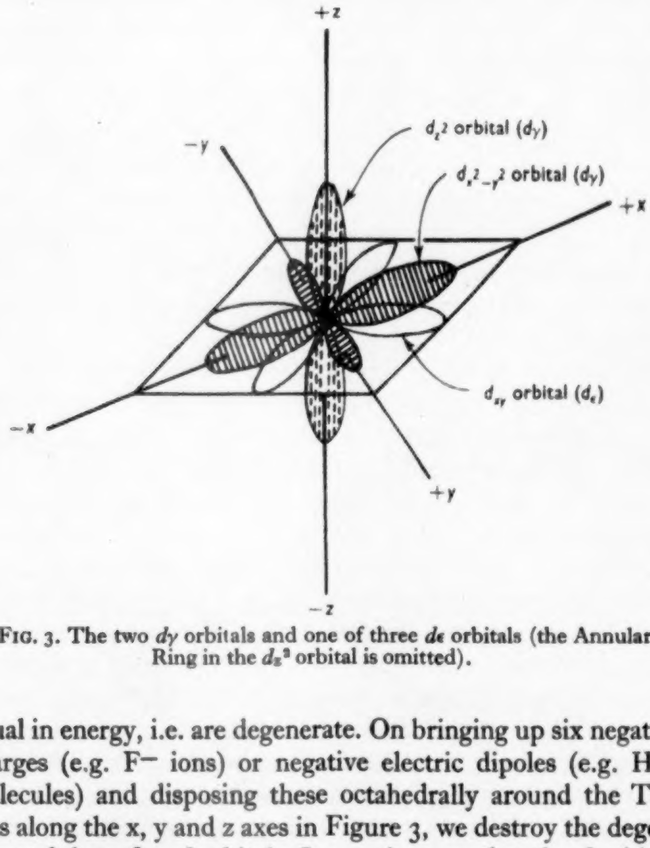


FIG. 3. The two $d\gamma$ orbitals and one of three $d\epsilon$ orbitals (the Annular Ring in the d_{z^2} orbital is omitted).

equal in energy, i.e. are degenerate. On bringing up six negative charges (e.g. F^- ions) or negative electric dipoles (e.g. H_2O molecules) and disposing these octahedrally around the Ti^{3+} ions along the x, y and z axes in Figure 3, we destroy the degeneracy of these five *d* orbitals. It may be seen that the *d* orbitals are of two kinds, two so called $d\gamma$ orbitals which have lobes of electron density pointing *towards* the six ligands and three so called $d\epsilon$ orbitals whose lobes of electron density point *between* the ligands. In Figure 3 we show only one $d\epsilon$ orbital, the d_{xy}.

The energy splitting of the orbitals (in an octahedral field) is shown in Figure 4, the separation between the levels Δ, being given in cm^{-1}. For $Ti(H_2O)_6{}^{3+}$ the value of Δ is 20,300 cm^{-1} which lies in the visible spectrum. Consider now the location of the single *d* electron in its lowest energy state (ground state); in these circumstances the electron will spend 1/3 of its time in each of the (equivalent) $d\epsilon$ orbitals. However, if sufficient energy be provided, e.g. if the solution be illuminated with white light, an absorption of energy at 20,300 cm^{-1} would provide the energy needed to lift the electron to a $d\gamma$ orbital. Now the laws of spectroscopy demand that for an allowed transition there must be a change in the subsidiary quantum number *l* of $\pm$ 1. Since ***both*** $d\epsilon$ and $d\gamma$ orbitals have the same value of *l* the electron transition is said by spectroscopists to be "Laporte Forbidden". In fact it does occur to a small extent because there are vibrations which perturb the pure *d* orbitals; nevertheless the transition still takes place with a relatively low intensity ($\epsilon \cong$ 1–5) only. As a result of this absorption band, the titanic ion in aqueous solution has a characteristic pinkish—violet colour. When there is more than one electron, e.g. two as in the $[V(H_2O)_6]^{3+}$ ion, the one electron transition can occur in two ways, even though it is simply written as $d\epsilon^2 \rightarrow d\epsilon' d\gamma'$. The final configuration ($d\epsilon' d\gamma'$) does not make it clear that there are two different dispositions of the $d\epsilon$ and $d\gamma$ electrons with respect to one another, which have different energy, *viz* $d_{xy}d_{z^2}$ and $d_{xy}d_{x^2-y^2}$, the latter being the configuration of higher energy. As a result, *two* bands are expected. Proceeding further one could promote *two* electrons to the $d\gamma$ orbitals giving a third band. These pictures of transitions in terms of orbitals are deliberately simplified and strictly speaking one should employ spectroscopic states which take into account interaction between the spin and orbital angular momenta.

Attention was drawn to the low intensity of the $Mn(H_2O)_6{}^{2+}$ and $[Fe(H_2O)_6]^{3+}$ absorption bands. These have d^5 configurations i.e. one electron in each of the five *d* orbitals. If an electron be lifted from a $d\epsilon$ to a $d\gamma$ orbital a transition from $d\epsilon^3 d\gamma^2$ to $d\epsilon^2 d\gamma^3$ occurs and this necessarily implies that the number of unpaired spins must change from five to three since electron pairing occurs in one of the three $d\epsilon$ orbitals. As a result the

transition is said to be *spin* forbidden as well as Laporte forbidden and the intensity of the absorption band is very small ($\epsilon \cong 0{\cdot}01$).

We must also mention briefly how the *d* orbital levels are split if the metal atom is at the centre of a tetrahedron of negative charges or negative dipoles (e.g. the $[CoCl_4]^{--}$ ion. For such a case the pattern shown in Figure 4 is *inverted*, the dγ being now of lower energy. This arises because whereas in the octahedron the lobes of electron density of the dγ orbitals point *towards* the ligands, in a tetrahedron they point *between* the ligands. In the

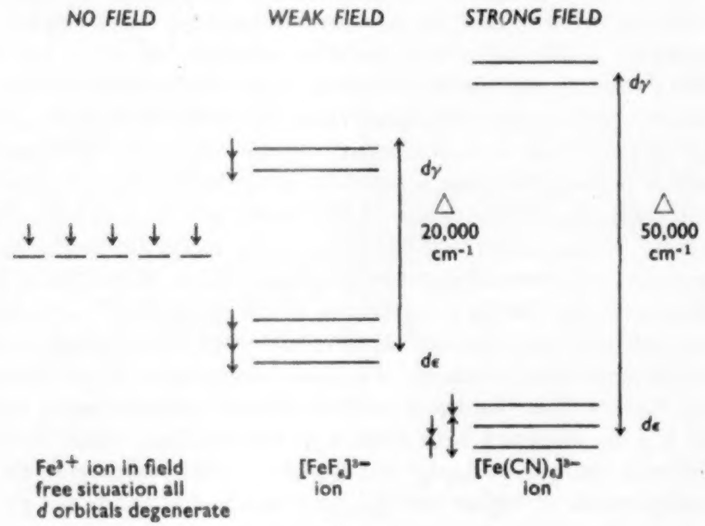


FIG. 4.

tetrahedral complex it is the dϵ orbitals which point more towards the ligands. However, the electrical field due to the four tetrahedrally arranged ligands is smaller than in an octahedral complex—for ligands at the same internuclear distances—and as a result $\triangle$ is only about 1/3 (theoretically 4/9) of the value for the octahedron. As an example, $\triangle$ for the $[CoCl_4]^{2-}$ ion is about 3500 cm^{-1}. This separation is so much smaller than the energy range for visible light ($\sim$ 14,000—25,000 cm^{-1}) that the colour of the $[CoCl_4]^{2-}$ complex is clearly not due to a simple d$\gamma \rightarrow$dϵ transition. The very intense absorption band ($\epsilon \cong 600$) observed in the red is generally attributed to a transition from the spectro-

scopic ground state (F) to a higher one with a different value of the orbital angular momentum (L), which corresponds with the subsidiary quantum number (1) for a single electron. (For $[CoCl_4]^{2-}$ the transition is believed to be $^4F \rightarrow {}^4P$.) Since there is a change in L the transition is allowed and hence a much higher intensity than that shown in a simple d→d transition is permissible, explaining the deep colour of the $[CoCl_4]^{2-}$ ion.

With the above background we now summarise, with examples, the different factors which affect the colours of inorganic compounds. In all cases we must bear in mind that anything which changes $\triangle$, *or* the number of bands, *or* their relative intensities, will alter the colour. The following are the most important.

(*a*) A change in the number of *d* electrons owing to a change of the metal ion. E.g. in passing from the $[Co(H_2O)_6]^{2-}$ ion (d^7) to the $[Ni(H^2O)_6]^{2+}$ ion (d^8) the value of $\triangle$ changes from 9,700 cm^{-1} to 8,500 cm^{-1} and the colour of the complex ion changes from pink to green. Note that the electron transition causing colour is clearly not that due to the smallest single electron change in each case since this has a $\triangle$ E value *less* than the range of values which correspond with visible light.

(*b*) A change in the number of *d* electrons owing to a change of valency. E.g. $[Cr(H_2O)_6]^{2+}$ (d^4) is blue but $[Cr(H_2O)_6]^{3+}$ (d^3) is green. Here there is also a marked increase in $\triangle$ owing to the higher charge on the complex ion.

(*c*) A change in the value of $\triangle$ owing to the use of different attached groups (ligands), an effect due to the effect of the latter on the strength of electric field. Thus, $[Cu\,(H_2O)_4]^{2+}$ is pale blue but $[Cu(NH_3)_4]^{2+}$ is violet. Indeed, ligands can be put in a series in the order in which they increase $\triangle$. Thus, for this purpose $H_2O < NCS^- < NH_3$ < Ethylene diamine $< NO_2^- <$ dipyridyl $\leqslant CN^-$

(*d*) A change in the value of $\triangle$ owing to a different stereochemistry (usually with change of ligand). Thus, whereas the octahedral $[Co(H_2O)_6]^{2+}$ has a pink colour the tetrahedral $[Co\,Cl_4]^{2-}$ ion is blue. The value of ϵ for the latter is one hundred or so times that for the former. As discussed above for the $[Co\,Cl_4]^-$ ion, the electron transition is not of the simple d—d type as for the octahedral complex. Similarly, whereas $[Mn(H_2O)_6]^{2+}$ is pink, tetrahedral $[Mn\,Cl_4]^=$ is green; also the $[Ni(H_2O)_6]^2$ ion

is green whereas the tetrahedral $[Ni\,Cl_4]^-$ has a deep blue colour. (*e*) Changes in Δ owing to isomerism. The compound $[Co(NH_3)_4Cl_2]^+Cl^-$ can exist in two forms; in one the two Cl atoms in the octahedron are adjacent (*cis*) and in the other opposite,

TABLE II

COLOURS OF RARE EARTH COMPOUNDS

All trivalent cations—the colour being almost entirely independent of the anion

I			II		
M^{3+} ion	Number of "f" Electrons	Colour	Colour	Number of "f" Electrons*	M^{3+} ion
La^{3+}	0	Colourless	Colourless	14 (0)	Lu^{3+}
Ce^{3+}	1	Colourless	Colourless	13 (1)	Yb^{3+}
Pr^{3+}	2	Green	Pale green	12 (2)	Tm^{3+}
Nd^{3+}	3	Red	Red	11 (3)	Er^{3+}
Pm^{3+}	4	Pink	Brown-yellow	10 (4)	Ho^{3+}
Sm^{3+}	5	Pale yellow	Pale yellow - green	9 (5)	Dy^{3+}
Eu^{3+}	6	Pale Pink	Pale pink	8 (6)	Tb^{3+}
Gd^{3+}	7	Colourless			

* Number in parenthesis gives number of *unpaired* electrons. Compare column I.

(*trans*). The first is violet, the second is green, owing to a different kind of splitting apart of the *d* orbital levels in each case.

It is of interest here to note Table II of the rare earths. For these ions the unpaired electrons in the incomplete shell ("f" in this case) are deep inside the atom and the levels are only slightly affected by the electric fields, arising from the anion. Note how the colours are complementary for shells with *n* and (14—*n*) electrons. Also it will be seen that f° and f^{14} shells are

colourless and the half filled (f^7) shell is also colourless—a feature which may be correlated with the behaviour of the transition metal ions.

It may be seen that in Figure 4 the separation between dϵ and dγ levels in the ferricyanide ion is very large and the electrons have been paired off in the dϵ set. Two electrons of opposite spin in the same orbital repel one another but the energy involved ($\sim$ 10,000 cm^{-1}) can be surmounted if the dϵ—dγ separation is very large as in the $[Fe(CN)_6]^{3-}$ ion. As a result of the far-reaching electron re-arrangements which occur in going from a spin-free (e.g. $[Fe\ F_6]^{3-}$ ion) to a spin-paired one [$(Fe(CN)_6]^{3-}$ ion) a marked change in colour is expected. This is indeed observed. In the complex compounds of tervalent cobalt we have all six *d* electrons in the dϵ shell. The many and varied colours of the cobaltammines are due to the fact that the ligands change $\triangle$ in a manner similar to that which occurs in the spin-free cases discussed above.

Charge Transfer Spectra

These arise either from electron transitions between atoms or between different molecular orbitals in a molecule. Consider for example the (concentrated) compound, silver iodide, (AgI) which is yellow. If this were a crystalline assembly of Ag^+ and I^- ions we might expect it to be colourless since Ag^+ has a d^{10} (closed shell) configuration, and the I^- ion also has an inert gas configuration. Although we can write the bond between these two atoms as ionic, i.e. Ag^+ . . . . I^- one can also envisage a covalent bond, i.e. Ag:X, the electron pair(:) being shared between the two atoms. Now if the energy difference between these two configurations corresponds with a quantum energy in the visible spectrum then absorption will occur and hence colour as a result. Charge transfer spectra are responsible for the colour of many metal oxides and sulphides and of compounds such as the complex oxides K_2CrO_4, $KMnO_4$ which absorb very strongly. The latter are of special interest since Cr(VI) and Mn(VII) have d° configurations. It is of interest to compare the colours of $[TiO_4]^{4-}$ (white), $[VO_4]^{3-}$ (V. pale yellow), $[CrO_4]^{2-}$ yellow and $[MnO_4]^-$ the colour increasing with the higher oxidation state of the metal.

Charge transfer phenomenon also occur when mixed oxidation states are present in many compounds. Thus, a mixture of green ferrous hydroxide and brown ferric hydroxide is black owing to metal-metal interaction *via* oxygen atoms.

Another intense colour arising from mixed oxidation states occurs in the compound formed when a solution of potassium ferricyanide ($K_3Fe(CN)_6$) is treated with a solution of ferrous sulphate ($FeSO_4$). The intensely blue precipitate formed has the formula $KFe[Fe(CN)_6]$. It can be regarded either as $KFe^{II}[Fe^{III}(CN)_6]$ *or* as $K\ Fe^{III}[Fe^{II}(CN)_6]$. The intense colour is considered to arise from a kind of oscillation of the electron between the two possible configurations.

Reference should be made briefly to colours which arise in certain crystals due to defects or the presence of impurities. Thus, irradiation of potassium chloride imparts a blue colour to the crystal. This colour disappears when the crystal is dissolved in water. It can be attributed to a very small number of colour centres containing potassium atoms. The origin of colour here is essentially a charge transfer effect. Finally, we draw attention to certain cases of colour where the effect ts due to the scattering of light; the colour is affected by the concentration, and size, of the suspended particles. Thus, when a beam of white light is passed through a suspension of finely divided freshly precipitated sulphur particles the emerging beam is red whereas the apparent colour of the suspension at right angles to the beam is blue. A similar effect is observed when milk is diluted with water. The explanation is simply that the red light is less scattered than the blue and as a result the suspension looks reddish viewed from the direction of the emergent beam and blueish at right angles. The red colour of the setting sun is due to this effect. Similarly, this is the reason why one uses orange or yellow fog lamps since this light is more penetrating in a foggy atmosphere.

EXHIBITS IN THE LIBRARY

(*a*) A display of samples of pigments; colour in surface coatings; the C.I.E. Chromaticity Diagram; samples illustrating the relation of particle size to colour; electron micrographs of pigment particles; and demonstrations of the effect of background, juxtaposition and light on colour, arranged by *Professor L. A. Jordan, C.B.E., D.Sc.*, and the *Paint Research Station.*

(*b*) Samples of rare earths and their salts, lent by *Johnson, Matthey & Co., Ltd.*

HOW CAN WE HELP UNDERDEVELOPED COUNTRIES?

By SIR NORMAN KIPPING, J.P.
Director-General, Federation of British Industries

Weekly Evening Meeting, Friday 23rd October, 1959

W. E. Schall, B.Sc., F.Inst.P.
Treasurer and Vice-President, in the Chair

PICTURE AN INDIAN PEASANT sitting on his haunches under a banyan tree. His possessions are a cloth round his middle and an eating bowl. He can expect to live about half as long as a European—or about as long as an Englishman in the early years of the Industrial Revolution: but if the monsoon fails, he may die next year. Picture next his cousin who went off a few years ago to Jamshedpur. He bicycles to work every day in the great Tata steelworks—as efficient as you will find anywhere; the house he lives in has electric light and running water; and the town's welfare services would be thought exceptional even in Sweden. The life of the one has not changed for centuries: the life of the other has never been seen before the twentieth century. Both are heirs to a culture that was mature and sophisticated when your ancestors and mine were running around the forests dressed in skins and blue paint. Their country is embarked upon a course that the world is watching with bated breath; for of all the newly developing countries India has perhaps the most at stake, both for her own sake and for ours. The contrast I have depicted is but one of the many that are typical of what we call the under-developed—or, better, the newly-developing—countries of the world.

You can argue if you like that in one sense all countries are under-developed—and so they are, in that known resources and present skills could everywhere be combined to produce more material wealth. Statistics which purport to compare the standard of life in different countries are notoriously unreliable but the broad picture they paint is clear enough. In very general terms it is not far wrong to say that the annual national income per head in America is about twice what it is in Britain, and that ours is about fifteen to twenty times what it is in Burma or Uganda. You can argue that South Sea Islanders with frangipani

in their hair and the trade winds blowing through the palm trees know more of the art of happiness than Londoners going home by train in the evening fog to a semidetached house in the suburbs. Personally, I doubt it: but that is not the point. For the fact is that the peoples of the under-developed countries themselves, through the articulate and the leaders among them, have made the choice—if indeed there really is any choice in the matter at all. They are determined at almost any cost to lift themselves up to higher material standards. Their vision may be a simple or a sophisticated one: whatever it is, they yearn to follow the road mapped out by the advanced industrial economies; for this road holds out to them a promise of an end to hunger, drudgery and fear. It would ill become us to question this will. We may well ask how it is to be accomplished, and why and how we who are further along the road can help. These are the questions that I wish to discuss.

Motives for help: political

There are I think three main motives for wishing to help the under-developed countries. One, which has been strong since the last war, is broadly political, and is based on the belief that by economic assistance we can insulate these countries against the blandishments of communism, make allies in the cold war and oil the wheels of emerging democracies. I have little faith in this view, which seems to me, at any rate in its more naive forms, to contain at least two fallacies. First, that the emotion of gratitude is one which plays any significant part in international relations. I do not mean this as a piece of cheap cynicism; but the job of Governments is to do what they think right and best for their people, and it is not reasonable to expect them to shape foreign policies so as to say thank-you to donors of aid. They may well do so out of a calculation of where their practical interest lies, but that is a different matter. Then, too, it is often imagined that as countries are progressively relieved of the more desperate economic pressures, they will naturally develop parliamentary democracies. But parliamentary democracy is a fine and delicate flower which it has taken us much time and effort and skill to cultivate, and which still requires constant and watchful tending. To suppose that it will easily or quickly grow anywhere is an

illusion; and it is arrogant to think that our particular form of government is necessarily best suited to countries at earlier stages of development and of utterly different histories and cultures.

Humanitarian

Another and better motive for wishing to help the under-developed world is one of conscience; and the next hundred years may well see the growth in the international plane of the ideas that have animated the development, within industrialised countries, of a greater concern by society for its weaker members. I for one have a great deal of sympathy with such sentiments. No one can fail to be moved, for instance, by the report of the United Nations Children's Fund that of the well over 1000 million babies born in the last twelve years, between 150 and 200 million died before their first birthday; and of the rest over 600 million were exposed to avoidable hunger and disease. Demographers say that in the next twelve years over 1500 million more babies will be born. What will be their fate? We must be passionately concerned with the answer to this heart-rending question, and not even the most hard-bitten can be content with purely economic answers. The real problem, however, is not whether we should help—of course we must—but how we can make our help effective.

Economic

That leads me to the third reason for policies of assistance to under-developed countries, which in my view is both sound and strong—namely economic self-interest. The high road of prosperity for all of us, developed and under-developed alike, lies in the growth of trade, the expansion of markets and the free movement of men, goods and money throughout the world. It is a matter of history that this is the road that has led to the enormous leap forward that the more advanced countries of the West have taken in the last two or three centuries—accomplishing in that time a far greater material advance than mankind had achieved in the whole of its history. No country can grow rich on its own. If Britain tried to be self-sufficient, it would be still, as it once was, no moie than an insignificant off shore island mea-

grely supporting a fraction of its present population. The point may be particularly obvious in our case, but it is just as valid all round the world: where would Japan or Sweden or South Carolina, be today if trade was confined within state boundaries? We have every reason to help other countries to join in a widening circle of trading communities, for their own benefit and for ours.

How then can the more developed countries best help the less?

Diagnosis

First we must help these countries to diagnose what they need, and why it is that they have not developed further. The answer is, of course, widely different from case to case, and often very difficult to find. Africa never invented the wheel for herself, and in large tracts a wheel was first seen only fifty years ago, and understood and adopted even more recently. On the other hand, many parts of the under-developed world once supported flourishing civilisations of sophisticated culture and considerable wealth—and did so often before ours was thought of. The Inca civilisation of Peru collapsed in the sixteenth century before a handful of tough Spaniards under Pizarro because it was so highly centralised that the removal of a handful of men at the top left it helpless, and because no-one then bothered about the remarkable roads on which the whole system was based. Similarly Roman civilisation was based on roads, but they were also great water engineers; and because their conquerors paid no heed to their water-works, what is now Tunisia degenerated from a lovely land of shady trees supporting ten million people, and when the French arrived eighty years ago it supported under one million. Even today it has under four million. Yet the water is still to be had there.

Population

Looking for causes, we see more often than not that population—or rather the balance between population and resources—is near the root of the matter; and the people are caught in a number of vicious circles. They are poor—so they do not have enough to eat—so they are too weak to work hard and produce more—so they are poor. They do not save—because their incomes are too low—because their productivity is low—because

they lack capital—because they do not save. And so on. The key role that capital and other help from outside can play is to break into these circles, and help to trigger off a new and expanding cycle of advance.

To these vicious circles medical science has added another, that of exploding populations; for it has raised expectation of life sensationally, while so far at least birth rates have stayed high. The result, ever more mouths to feed and hands to employ; and great difficulty to run fast enough even to stand still. That is why Pandit Nehru and the Indian Government are backing the movement to spread birth control among their people. Meanwhile it is also another factor which ought to modify the application of Western industrial techniques. In the West labour is increasingly one of the most scarce and expensive of the factors of production: hence our emphasis on labour-saving and our trend, particularly marked in America, to put ever more capital and power behind the elbow of each industrial worker. But in these countries labour is, and may long be, abundant and relatively cheap; it is capital, and sometimes land, that are scarce and dear. So methods which are the most economic in the West are not necessarily so in the East, and vice versa; and there is room for ingenuity and inventiveness in response to this different pattern.

The basic dilemma, however, is that which Robert Garner, the President of the International Finance Corporation, put his finger on when he said: "The bulldozer can move almost anything except a habit or an idea." The hardest and the slowest thing to change is man. And the extent and depth of the changes in ideas and habits that are needed are really daunting.

Impetus must come from above

Whatever the reasons—and I suggest they are many and deep and complex—we face the fact that by and large in the underdeveloped countries the springs of individual initiative and resource in economic matters seem in the past to have been lacking, and the restless quest of countless individuals which made our Western prosperity has generally been absent. If, now, there is a new awakening and determination, the transition they have to make into the modern world will be harder for them, for the pace is hotter and the scene infinitely more complicated than it was

when we began to make our way. The drive does not come from below—as it did with us, and for the most part still does. It comes from the top downwards, and from outside—from the elite few in each country who are in contact with the outside world and who have educated themselves in modern techniques; and from those from more advanced countries who come to trade or to teach, to research or to invest. This fact of itself goes far to account for the tendency to think in terms of the grandiose schemes, often at the expense of the equally important little things; and it creates the additional problem that the educated few tend, by the very fact of their education, to be cut off from the mass of their own people.

In such a situation our own experience at home gives little guide, for America and Britain and the other industrial leaders of today did not grow rich through development plans or agricultural extension schemes of Point Four. There is need for new institutional forms and new links with institutions in the more advanced countries, and in general for a flexible and experimental approach. And I am sure we should not generalize, or expect to find solutions which will apply everywhere. So may I throw out by way of example a few pointers which seem to me suggestive?

In parts of Iraq there is little to do on the land between the end of the summer crop and the sowing of the winter crop. So a system used to be in force whereby the month of October was spent in cleaning irrigation canals. Each farmer supplied labour for silt-clearing, and everyone turned to, to keep up their local canal which supplied their farms. At the end of the month they killed sheep and had a party with singing and dancing. Very sensible. But then Iraq joined the League of Nations and signed a convention at Geneva condemning "forced labour" and the system was abandoned. So now the Government has to clean the canals with expensive mechanical draglines—if the job gets done at all—and the local people sit around and watch. Surely less sensible.

In the north east of Brazil, there is a vast area which is hot and dry with little irrigation, few roads, no electricity. Until a few years ago, subsistence farming by small holders, on lands they did not own, was the order of the day. The farmers were engaged in a relentless battle against hunger and disease; education was lacking, and so was credit to enable them to develop their land,

build a farmhouse, or buy cattle and seed. As a result they were flocking to the cities and creating problems there nearly as bad. So the State Government set up a credit association and, with the help of the United Nations Food and Agriculture Organization, they have worked out a system of supervised credit. The distinctive feature of this is that the credit is accompanied by technical advice in its use. Instalment loans are given for such improvements as fences, small dams, wells and replanting; for water receptacles, cooking stoves, latrines; or for the building of of a new home or a store. And advice and training go along with the loan, so that the effect of both is magnified. Similarly the World Bank is developing techniques of leading credit right down the line through local industrial and agricultural banks so as to harness local knowledge and assessment of credit-worthiness in combination with local technical advice and training.

A few years ago a British firm making agricultural equipment got an order from Malta for two of their smallest rotary hoes then another for six, and another ten. They were surprised at this, for they had no representative there, so they sent a man out to see what was going on. The explanation was this. A tramp steamer had hobbled into Malta after a bad accident in the Mediterranean, and what was left of its cargo had been put up to auction. Thus a local ironmonger had acquired in a job lot one of this firm's rotary hoes, bound for points east. He was intrigued, read the instructions, tried it out in his garden, and was delighted. Then a neighbour looked over his wall—hence the first order—and so on. Soon the firm was selling £60,000 worth a year in Malta—a market that it had never occurred to them to think about before.

Capital: its nature

So I think that when we look at an under-developed country to try to see what it lacks and what it needs, we must guard against a tendency to do so from too Western a viewpoint. We may tend to think of capital investment in terms of what shews up in official statistics, and where this is absent or small we think we are looking at stagnation. But if a man by his labour improves his field—builds an earth wall perhaps, or digs out a drain—or if he plants another cocoa tree, he is accumulating capital; and if

thousands of his neighbours are doing it too, this capital investment, which passes unrecorded, may be just as real and important as the building of a cement factory which is opened by the Minister of Works.

Capital depends for its fructifying role on proper use and appropriate incentives for its use. It has to be produced before it can be invested. And nowadays the demand for it exceeds the supply; and there are many attractive opportunities for its deployment near home. Quite apart from the huge demands made by wars hot and cold, the pace of technical and scientific change in the advanced countries is making huge demands, not only for expansion, but for replacing what was new yesterday but is obsolescent today. Moreover when capital is invested—in factories in harbours, in power stations or what you will—the new assets so created have to be tended and renewed, or they will quickly grow useless. Harbours must be dredged, machines serviced, roads repaired; and so there is a running cost, often heavy, left behind after the provider of the investment has gone. This is something far too little understood, in developed as well as underdeveloped countries, and helps to feed the illusion that capital can—or should—simply fall like manna from a Western storehouse on to the hungry desert beneath.

How to attract capital

All this has a bearing on the ability of newly developing countries to attract from outside the capital that they so badly need and to put it to the best use. It is not reasonable or realistic for any country to expect traders, industrialists and investors—at home and still less from abroad—to venture upon enterprises within its territory unless it creates and maintains conditions which inspire some confidence of security and success. There are countries which are crying out for capital, and yet local funds are invested abroad because their *own* people have no confidence that it will be safe and can earn a return at home. There must be reasonable assurance that production will not be so shackled by restrictions and cost-increasing regulations that it cannot be profitable: that there will not be discriminatory taxation; that goods and money and people can move back and forwards with reasonable freedom; that assets will not be expropriated without

fair compensation. A country must, and ought to stand a far better chance of attracting help if it so orders its affairs as to offer good prospects that the help will be put to good use, and will not run away into the jungle or the sand.

How to use capital

But here there is another tendency we should be on guard against—and one to which both the West and the East are prone—that of thinking too exclusively in terms of the big spectacular project. Almost every developing country runs a Government-owned or subsidised airline; and monster dams, power stations and steel mills tend to become symbols of emerging national pride and prestige. For the international agencies or advanced countries who put up the money, and often build the project too, they are equally attractive because they have all the glamour of the most up-to-date techniques, and because those who design and build them have a natural professional pride in building the best and biggest they know how. For both sides they are easily recognizable monuments of achievement: everyone can understand and see what has been done. This tendency is natural enough, and nothing to sneer at; but it may sometimes saddle the receiving country with a continuing and uneconomic burden—for instance, of making steel, as they do in Egypt, from imported coal at far higher cost than they could import it. This may have the consequence not of raising living standards but lowering them through mounting prices. Even more serious may be the burden on the local technical and administrative skills, and the lack of all the ancillary facilities we tend to take for granted. And in the end I most fear disillusionment, when the local people find that the benefits they were led to expect are long in coming, and that life for the masses goes on as before. It is far from my thoughts to decry the big project, which can often bring big benefits: I do suggest, however, that there are many cases where the doing of little things in large numbers may be of more enduring and sounder value than a few big things, or at least where the little things need to be done alongside the big.

Tractors need trained men used to machines to drive and service them, and they need petrol and oil and spares: but when half the world's acreage is still reaped with the sickle, there is a

vast improvement to be had simply by replacing the sickle with the scythe. Given water, perhaps from a new dam, irrigation can often be tackled by clearing out old water-courses and digging drains as well as by new canals with the latest control devices. Simple but effective things can be done to improve village springs and wells without installing modern waterworks or purification plants which are too complicated for village use.

In most countries the villages do not lack local craftsmen, for they make nearly everything for themselves: so there is a joiner and a mason and a tinsmith and a shoemaker and a weaver and so on. If ways can be found of putting a better tool or a simple machine in their hands, and of enabling them to learn better methods of working local materials, as much may be achieved as by the new factory which turns out millions of pairs of boots and shoes every week, with all the attendant problems of an uprooted labour force. India is doing both—sending cadres of trained helpers into the villages, and developing her modern industries as well. I am sure this is the right approach.

Education

That brings me to the need for training and education, which is implicit in all I have said. This course must be a major theme—perhaps the most important of all— in policies of development for all these countries we are considering. It is hard to exaggerate the revolutionary effect of getting rid of illiteracy: to teach a man to read is to show him a new world. On the international level it is not simply a question of a one-way traffic of people coming to Europe and America for training. Both the United Nations Expanded Programme of Technical Assistance and the Colombo Plan take pride in the exchange of students that they promote between the different countries, who can in this way share the various facilities that each has mounted. The creation of still further opportunities for spreading and sharing knowledge and experience throughout the world is clearly of the first importance.

Industrialists as well as Governments, in this country and in many others, are lending a hand with this. For instance, the F.B.I. runs a scholarship scheme for overseas graduates; and the multiplication of such schemes in many countries must, I am sure, make a significant contribution. In Britain at least 40,000 over-

seas students are now receiving instruction, some 27,000 of them from Commonwealth countries. Industry is also lending a hand along with others with what is in the end even more important—namely the building up in these countries of their own educational institutions, universities, technical colleges, schools and so on. For example, the Governments of India and the UK and my own organisation are working together on a scheme for Britain to help in the setting up of a new College of Engineering and Technology in New Delhi.

I think, too, that we can help by drawing attention to the need for a sensible balance in educational programmes. It is of little help to any country to produce a class of highly educated but disgruntled men who cannot find employment for their skills, while at the same time there is a desperate shortage of qualified vets, foresters, social scientists and technologists of all kinds. And that illustrates an important point that is easily overlooked. Our industrial civilizations depend for their working not only on scientists and technologists, engineers and chemists, but also on a host of ancillary but indispensable professions—accountants, surveyors, valuers, actuaries and so on. And most of all on good government, to secure internal peace and the rule of law; to manage the currency; to provide the basic services—elementary education, public health, communications. This framework of orderly government requires much skill and devotion to build up and maintain, and places a severe strain on the resources of emerging countries.

Our policies

I hope I am not giving the impression that I see need for improvement only in others. Indeed, I think that many of our own policies badly need revision if we are in earnest in our desire to help the under-developed countries to advance. Probably we could do many of them as much good by following helpful policies at home as by any amount of direct aid. Let me give a few examples. In spite of the progress since the war in the O E E C, we all still have a fair way to go to get rid of the thickets of artificial barriers to trade—tariffs, import quotas, exchange controls—all of which narrow the markets of the world. The General Agreement on Tariffs and Trade has drawn attention to the lagging

behind in the freeing of trade in agricultural produce, as opposed to industrial goods; and to the dire effect of many farm support policies in industrialized countries on the economies of less developed countries which largely depend on agricultural exports for their living.

The doctrine that the best thing we more advanced countries can do for the younger countries is to open our markets to them is not an easy one for some industrialists in the West, and it does not preclude gradual rather than over-night adjustments. But it comes, I think, very near to the heart of the matter. Without access to our markets, no foreseeable amount of economic aid and technical assistance can possibly suffice. This is a lesson we in the West—and I have America much in mind as well as Europe—have not yet fully digested.

I should not be surprised if any visitor among you from a newly-developing land were to say to me: "Yes, what you have been saying is all very well; but in my country we simply cannot afford to wait while all your common-sensical recipes slowly mature. If that is the best you can do, perhaps we should try the communist way." I can understand such a point of view: the inevitability of gradualness is a hard doctrine. But I believe it is a true one and I would expect an indiscriminate outpouring of funds to bring, not quicker progress, but quicker disillusionment and waste. The ill-fated ground nuts scheme is a text-book illustration. At the same time, I believe that progress can today be much quicker than it was when the industrial leaders of the West were themselves starting on their way. We had to accumulate all the capital we needed as we went along; discover the knowledge; pioneer the techniques; and make all the mistakes of the man who does it first. The newly developing countries can draw on all this treasury and with our help go all the faster. They cannot, however, go faster than the reality of their circumstances makes possible; and with the best will in the world the bulk of the job will have to be done by their own efforts.

The fundamental dilemma has been expressed by Pandit Nehru: "The difficulty comes in always between the needs of today and the demands for tomorrow. And if you want a surplus, well you have to be strict with yourself in the present generation; and democracy does not like stinting the present."

That, as he pointed out is where an authoritarian government has an advantage. Yet I for one do not shrink from Mr. Kruschev's challenge to the West to an economic race. If we must vie with one another, let it by all means be to see who can most speedily improve the lot of the people in all the newly developing countries.

Be that as it may, I would be the last to pretend we know all the answers: I am sure we do not. We are already putting forth a formidable effort—through the United Nations and its agencies; through the Colombo Plan; direct from one country to another; through charitable foundations; and by private initiative and enterprise. It is impossible to put a figure on all this.

But all of us in the West should ask ourselves whether we are yet doing enough, whether our efforts measure up to the task. We can, and no doubt will, better our techniques. And both the developed and the developing countries can do much more to devise and pursue policies that will foster a steady expansion of trade throughout the free world. In the long run this is the surest way of keeping not only the growing economies, but also our own, off the rocks, and of expanding prosperity all round.

I end with two bright hopes for the future, one for the doctors and one for the engineers, which between them could make possible a great step forward in the material standards of the underdeveloped world. First, a simple, cheap and fool-proof method of birth control—to give India and Egypt and China a breathing space in which their output can catch up on, and run ahead of their expanding populations. Second, the development of cheap and simple 1000 kv nuclear-fuelled power stations. Cheap and plentiful power means, among many other things, water, which will be pumped and piped from as far as necessary or distilled from the sea.

I was brought up to believe that the usual entitlement is three wishes. I have given you two. I leave the third to your own imagining.

EXHIBITS IN THE LIBRARY

A display of photographs and pictures of underdeveloped countries, lent by the *Central Office of Information, United Nations Food and Agricultural Organisation,* and *United Nations London Information Centre.*

PLANT VIRUSES: WHAT THEY ARE AND WHAT THEY DO

By F. C. BAWDEN, F.R.S.
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Weekly Evening Meeting, Friday 30th October, 1959

H. D. Anthony, M.A., B.Sc., Ph.D.
Vice-President, in the Chair

To understand the interest in and controversies about the nature of viruses, it is necessary to appreciate the spirit of the time when viruses were discovered. This happened in the 1890's, soon after the germ theory of disease had become firmly established and most pathologists confidently thought that, for each infectious disease, they would be able to find a specific causal micro-organism. This confidence was shaken but by no means upset by Iwanowski's discovery that the cause of tobacco mosaic passed through a bacteria-proof filter and that a seemingly sterile fluid free from any visible organisms caused mosaic when inoculated to plants. Indeed, Iwanowski himself was so imbued with the idea that mosaic was a bacterial disease that he attributed his result either to a leaky filter or to the passage through it of a bacterial toxin that caused mosaic. Beijerinck, who repeated Iwanowski's results, disagreed with his conclusions and was the first to suggest that what are now called viruses differ fundamentally from even the smallest organism. He set the stage for the controversies by calling the cause of tobacco mosaic a "*contagium vivum fluidum*", but neither he nor his few followers could produce any positive evidence on the identity of viruses that overcame the accepted idea that viruses were essentially organisms, differing from bacteria only in size and ability to multiply on artificial media. The similarities between the behaviour of viruses and bacteria were too apparent: not only were many virus diseases clinically like bacterial diseases, but viruses obviously multiplied in susceptible organisms and in doing so sometimes gave rise to offspring with properties different from themselves, and the abilities to multiply and mutate were accepted as the prerogatives of organisms. The inability of viruses to multiply except in organisms was not a conclusive argument against their being

organisms, because some visible organisms, various fungi and bacteria, also seemed to be obligate parasites.

Positive evidence that viruses differ fundamentally from bacteria had to wait until the middle of the 1930's, when plants infected separately with several different viruses were shown to contain specific nucleoproteins, some of which, such as the one from plants with tobacco mosaic, had some anomolous properties, including forming liquid crystals and showing the phenomenon of anisotropy of flow (streaming birefringence) strongly. Much evidence was gained relating these nucleoproteins with the viruses, and although their identity could not be proved, there was no doubt that, if they were not themselves the virus particles, these particles must be still smaller and so still further removed from bacteria.

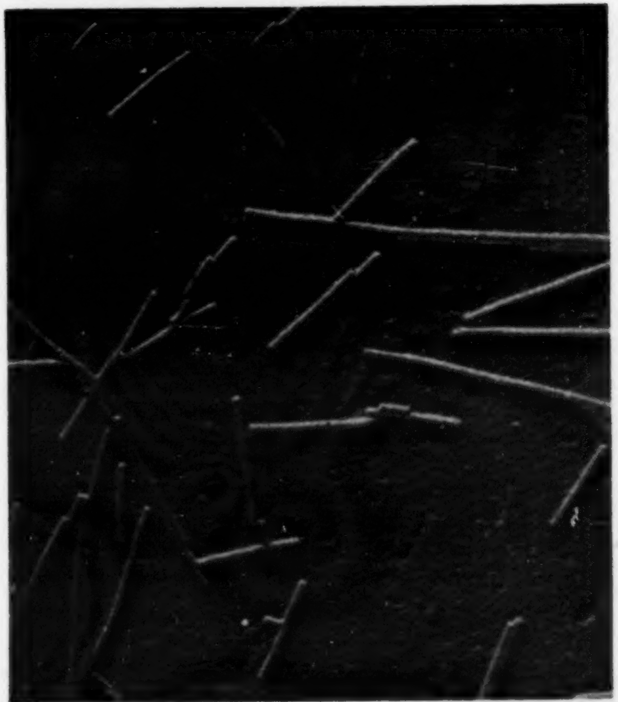
The optical and other physical properties of purified preparations of tobacco mosaic and some other viruses showed that their particles were grossly anisometric, whereas still others formed solutions with normal physical properties and some of these crystallised in forms that showed their particles to be isometric. The fact that the nucleoproteins formed crystals or liquid crystals made their study possible by X-ray crystallography, which gave the first precise measurements of virus sizes and the first information about their internal structure. It showed that viruses are made of sub-units, all of a similar size and arranged with a three dimensional regularity that conflicts strikingly with the varied and continually changing internal composition of a cell. Also, chemical analyses of the purified viruses showed only two main components, protein and nucleic acid, a striking contrast to the many substances contained in even the simplest bacterium. It was the ability of these viruses to crystallise that attracted most attention at the time, but this had little biological significance, except perhaps to indicate a uniformity of particle size that fits ill with the idea of multiplication by binary fission, which inevitably implies a particle first swelling and then splitting into two smaller ones. What was much more significant in separating viruses sharply from organisms, was their chemical simplicity and the fixed arrangements of their component parts, features that related them more closely to individual components of cells, such as the "normal" nucleoproteins, than to whole cells.

Some workers, impressed by the apparent physical homogeneity of purified virus preparations, did not hesitate at this time to put viruses in the category of molecules, and for some years there was the apparent paradox of the same entities being called "organisms" by some people and "molecules" by others. Although this suggested an irreconcilable difference, it is now of historic interest only. Indeed, it was a conflict that should never have arisen, for to apply either word was to prejudge what should have been an open issue. Because viruses are less complex and structurally different from organisms does not mean they must be molecules, a word that implies a precise knowledge of chemical structure unattainable with such large particles (equivalent molecular weight of many millions) and demands an unchanging structure that conflicts strikingly with the great mutability of viruses. There is a range of cell components that approximate to viruses in size and general composition, and some of which behave rather like viruses in seeming to reproduce and vary; if analogies for viruses are to be sought, it is among these biologically active components of cells rather than among whole organisms or the simple molecules of the chemist.

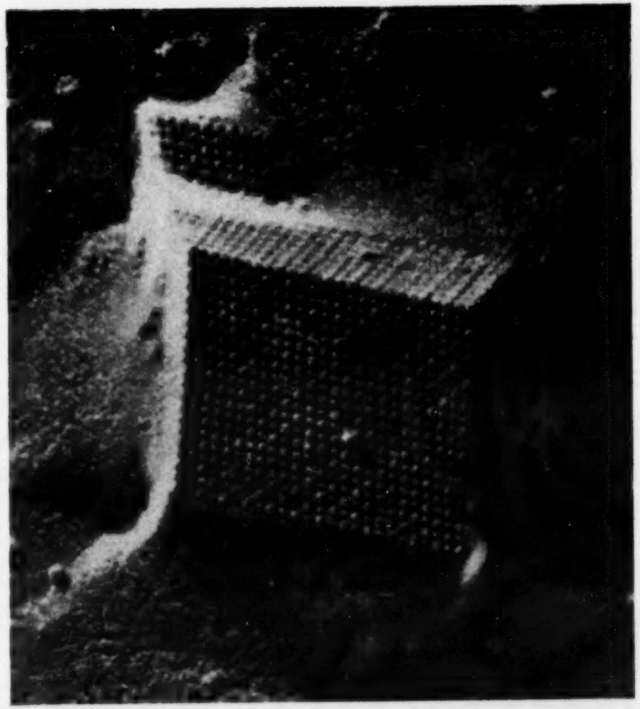
The intracellular habit of viruses had long been recognised, but with the new knowledge about viruses it took on a new significance. The time had come to abandon the old idea of virus diseases as the equivalent of one organism preying on another and to replace it with a new one, of the virus becoming an integral part of the host cell, adding its activities to those of other cell components to determine the functioning of the whole infected cell, and with the diseased condition reflecting aberrations in the nucleoprotein metabolism of the host.

Structure of virus particles

With the development of the electron microscope, particularly when combined with the technique of "shadow-casting", direct observations on the sizes and shapes of virus particles became possible. These showed that plant viruses with anisometric particles are of two kinds; one, of which tobacco mosaic is the best known, seemed to be rigid rods (Plate IA), and the other of seemingly flexible threads; also the isometric particles seemed to be spheres (Plate IB). However, later results, from X-ray crystallo-



A. Electron micrograph of shadowed preparation of tobacco mosaic virus showing apparently rigid rod-like particles 15 mμ wide and of varied length.



B. Electron micrograph of a small crystal of the Rothamsted tobacco necrosis virus, showing the apparently spherical particles fitting into a three-dimensional lattice. (Photograph supplied by and reproduced by permission of Dr. R. W. G. Wyckoff).

PLATE I

graphy and from electron microscopy of "stained" viruses, have greatly modified these earlier conclusions. Thus tobacco mosaic virus is not a rigid rod composed of uniform nucleoprotein particles, but is a hollow tube with a deeply grooved surface, built up from protein units of a size equivalent to a molecular weight of about 18,000; these units are set in spirals around the long axis of the particle, with 49 units to every three turns of the spiral (PlateII). The nucleic acid occurs as a thread deeply embedded in the protein, with the chain direction of the thread directly related to the spiral arrangement of the protein units. Less is known about any of the other anisometric viruses than about tobacco mosaic, but those that have been examined critically also seem to have the same general type of construction. Similarly, ideas about the particles that appeared to be spheres when examined as "shadow-cast" preparations have had to be changed; these now all seem to be polygons, with the outside of uniform-sized protein units and the nucleic acid carried internally.

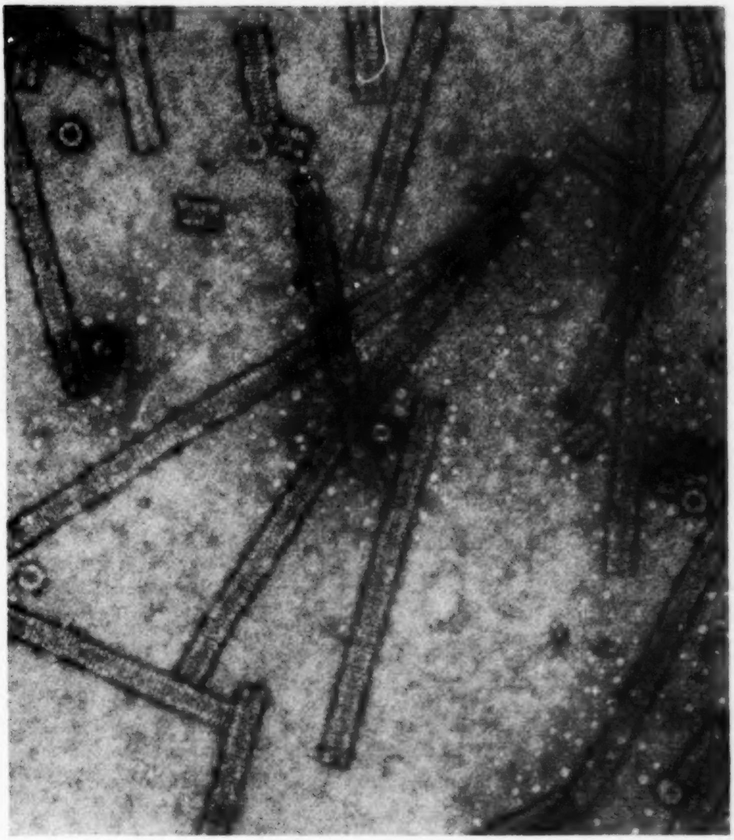
All the viruses from flowering plants that have yet been examined have contained ribonucleic acid, but this is not true of all viruses. In particular the bacteriophages contain deoxynucleic acid; these are also larger and morphologically more complex than any viruses yet found infecting flowering plants, a complexity that should certainly prevent the word molecule from ever again being applied to virus particles. Bacteriophages also differ strikingly from plant viruses in being able unaided to enter and leave their hosts, an activity for which their morphology is beautifully adapted. Tadpole-like bodies, they have a hexagonal head, with a protein envelope surrounding the nucleic acid, and a tail consisting of a protein sheath surrounding a hollow core and ending in six threads, which aid the adsorption of the particles to susceptible bacteria. Some of the tail protein is contractile, and contracts when the tail has become attached to a host cell. The tail also carries an enzyme able to soften the bacterial cell wall.

Infection happens by the bacteriophage attaching itself tail first to a bacterium, after which the nucleic acid moves from its head through the tail and into the bacterium. The tail and protein envelope remain outside, but the new bacteriophage particles that later emerge from the infected bacterium nevertheless are complete with heads and tails. Hence the protein does not repro-

duce itself, because it never enters the infected cell. The only replicating part seems to be the nucleic acid, which not only engineers more of itself but also of the various types of protein that go with it to make up the whole virus particles. The virus nucleic acid and protein are synthesised separately inside the infected bacterium and then brought together in a final piece of assembly that differs fundamentally from any process biologists would normally describe as reproduction.

For more than 20 years after they were first discovered, the nucleoprotein particles of plant viruses seemed to be replicating entities and the minimum infective units, but this also is now known to be untrue. As with the bacteriophages, the protein does not reproduce, for infections can be initiated by fragments of virus particles that consist largely, and possibly exclusively, of nucleic acid. There is circumstantial evidence, too, that, as a first step in infection with intact virus particles, the nucleic acid and protein separate, and that the nucleic acid and protein are synthesised separately and then combined to give the complete, stable particles. The process of assembly from constituent parts seems not to require any very complex system, for when tobacco mosaic virus is disrupted *in vitro* by alkali the parts reassemble into the characteristic rods when they are acidified.

The viruses whose gross chemical constitution has yet been determined are a varied collection differing in size, shape, host range, ratio of nucleic acid to protein, stability and almost every other property, yet all have consisted largely of nucleic acid, either ribose or deoxy, and protein. Whether this is true of all invisible pathogens, which is the simplest way to define viruses, only time will tell, but it can be said that this is now the expectation and finding one that differs radically will be a major discovery. There is one obvious possibility. The protein of viruses such as tobacco mosaic may have many roles but the only one yet established is to protect the nucleic acid against potentially inactivating environments. This is no minor role, for the infectivity of the nucleic acid when separated from its protein cover is ephemeral. However, if there are nucleic acids that are more stable *in vitro*, then these might act directly as viruses without any protein wrappings; in other words, some viruses may be nucleic acid only.



Electron micrograph of stained particles of tobacco mosaic virus protein, showing the hollow core and the regular pattern along the rods.

PLATE II

Some effects of viruses

The economically important effect of viruses is to make plants diseased and decrease their yield. Infection of plants has more lasting effects than in animals, for plants lack the antibody-forming mechanisms of animals. In animals, virus diseases that are not lethal are usually transient affairs; they may be unpleasant but within a few days the defence mechanisms operate and the viruses are overcome. By contrast, a plant once infected usually remains so for the rest of its life. Exceptions are plants in which viruses cause only local infections, but in these viruses are not troublesome. To be economically important a virus must infect a plant systemically, that is, from a single entry point it must spread through the plant and invade most or all such parts as leaves, stems, flowers, fruits and roots. Viruses usually persist in vegetative tissues for as long as these tissues are viable, and methods of vegetative propagation will perpetuate in the progeny any virus the parent stock contains. This is the reason for "clonal" varieties of such plants as potato, raspberry and strawberry, which are propagated by tubers, runners and the like, losing their cropping power after some years in cultivation. A few viruses also invade the seeds of plants, but most are not seed-transmitted and sowing seed from infected parents will usually give virus-free seedlings. The widespread, mistaken belief that vegetative reproduction is debilitating comes from the fact that, whereas reproduction from seed usually cleanses the progeny from viruses accumulated by its parent, vegetative reproduction does not; provided a clone remains virus-free, however, there is no reason to think that vegetative propagation leads to loss of vigour.

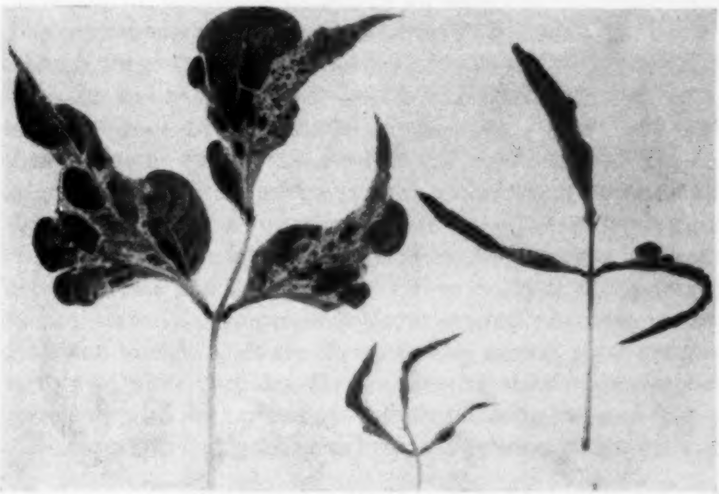
Until recently, virus infections had to be accepted as permanent, and useful clones that became diseased had to be abandoned, but now cures are almost routine. One therapeutic method rests on the fact that infection is not always fully systemic, for some viruses do not invade the growing tissues at the stem apex; by carefully excising apical meristems and culturing them on agar medium, virus-free lines have been regained of some clonal varieties previously all infected. The second method rests on the fact that many viruses do multiply in plants growing at unusually high temperatures, and plants can be freed from such viruses by growing them continuously for 2–3 weeks at about 36°C. (Plate IIIA).

How viruses manage to move through plants is still largely unknown, but those such as tobacco mosaic obviously do so in two ways. When they are inoculated to a leaf, there is a period of a few days while the virus multiplies at the infection site and spreads only slowly through the parenchymatous leaf cells. When it reaches the veins, however, it moves so much more rapidly through the vascular system that within a few hours it reaches the uppermost leaves and the most distant roots. The fact that the viruses ultimately invade most tissues means that all parts can show effects. Signs are most commonly shown by leaves and take a variety of forms. Loss of chlorophyll is probably the most usual; the whole leaf may go yellow, or it may show a pattern of light green or yellow spots, blotches or rings, or leaf cells may be killed, when the leaves will show necrotic spots, rings or blotches (Plate IIIA). A thriftless plant with yellow leaves that does not grow vigorously when well fed should always be suspected as being virus-infected, but leaf mottlings and ringspots can have other causes. Leaf symptoms of greater diagnostic value are those in which the leaf takes on new forms, with leaves becoming tendril-like or with leafy outgrowths produced from the veins (Plate IIIB).

Stems show symptoms less often than leaves, but green stems sometimes have rings or spots on them similar to those seen on leaves. Some viruses alter the character of stems; thus swollen shoot virus of cacao stimulates cambium to unusual activity and the extra vascular tissue produced makes characteristic local swellings in the stems. One host, which normally has spines on its stems, becomes spineless when infected with this virus. Rubbery wood virus produces no obvious external symptoms on stems, but it prevents wood from hardening normally and apple shoots of a size that would normally snap when bent can be tied into a knot without breaking. Many of the internal discolourations of potato tubers are also signs of virus infection. The proliferation of side shoots is also a frequent effect, giving unusually bushy plants or "witches' brooms".

Flowers of virus-infected plants are often misshapen and small, but of greater diagnostic value are the characteristic colour changes they undergo. Blood red wallflowers, for example, become streaked with yellow, and pink chrysanthemums with

A. Leaves of *Abutilon striatum*: the upper two are infected and variegated, the lower two are uniform green and from a plant freed from virus by growing it at 36°C continuously for 28 days.



B. Leaves of French bean plant mottled and deformed by infection with a strain of tobacco mosaic virus.

PLATE III

white. This phenomenon is fairly general but is best known in tulips, and "broken" tulips provide the oldest records we have of plant virus diseases, for Dutch painters in the sixteenth century were attracted by variegated blooms, which are portrayed in many flower studies of that time. All tulips when first raised from seed have flowers of a uniform colour, but when they become virus-infected the flowers "break" or become variegated. The condition is then permanent for the virus is perpetuated through the bulbs indefinitely, and some virus-infected lines have been cultivated under specific varietal names for many years. Another characteristic effect of one group of viruses is to produce the phenomenon known as phyllody, whereby flower parts become leaf-like.

Fruits, too, show many different effects from infection by viruses: a decreased size is the commonest, but shape, colour, texture and flavour may all be affected. The effects are reflected in such names of virus diseases as "chat fruit", "bitter pit", "stony pit", "plum pox" and "little cherry".

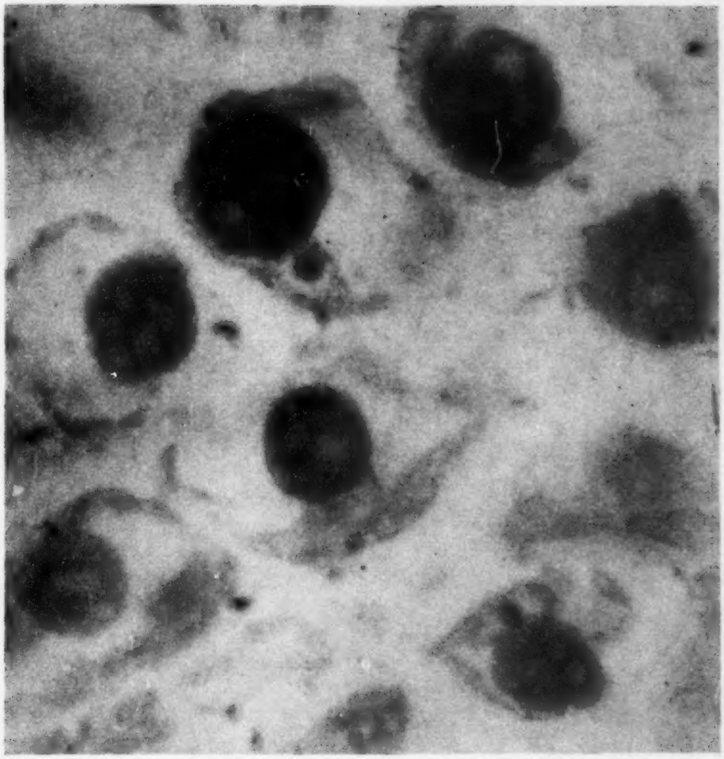
Within the scope of this discourse it is possible only to indicate the range of effects produced by viruses and emphasise those of diagnostic value. Specific diagnosis from symptoms, however, is rarely possible because viruses can cause very different symptoms in different plants or even in different varieties of one species of a plant. Also, individual viruses exist in many variants or strains that cause widely differing effects in the same variety of one plant. The commonest effect of tobacco mosaic virus in White Burley tobacco, for example, is to deform the leaves slightly, to decrease their size and to change their leaves from a uniform dark green to a pattern of different shades of green and yellow. However, there are some strains that produce only necrotic local lesions, others that rapidly kill infected plants, others that turn the plants almost wholly yellow and still others that produce no overt signs of infection. There is still little information about the reactions between virus and host that determine the type of symptoms caused. However, symptoms do not arise simply because amino-acids and nucleic acids are diverted from normal plant components into virus particles, for the severity of symptoms is not correlated with the amount of virus contained in infected plants. Tobacco plants can be killed or crippled by some viruses that do

not achieve a thousandth the amount reached by strains of tobacco mosaic virus that have little effect on the growth or appearance of tobacco plants. Also, some viruses reach high concentrations in some hosts without causing any obvious abnormalities; such hosts, the "typhoid Marys" of plant pathology, often provide sources of infection for other plants, doubly dangerous because they are usually unsuspected. The type of symptom is set primarily by the genetic constitution of the virus and host, but it also depends greatly on the environment in which an infected plant is growing. By changing temperature or light intensity the appearance of virus-infected plants sometimes changes from acutely diseased to almost normal.

Viruses also produce many effects inside plants. Some of these simply reflect the external changes, for instance collapsed cells in necrotic lesions, and chloroplasts smaller and paler than normal in yellowed parts of leaves, but others are characteristic of virus infections and are valuable in diagnosis. These specific effects are to produce abnormal bodies, the intracellular inclusions, which differ in type from any component of uninfected cells. The inclusions are commonly in the cytoplasm but some form in the nucleus. Some are true crystals and these seem to consist largely and possibly exclusively of virus particles. The others differ greatly in form and size in different diseases; most are vacuolate, and some are clearly defined, large, spherical bodies that occupy much of the cell volume and dwarf the nucleus (Plate IV); others are small and amoeba-like, variable in shape and less clearly distinct from the host cytoplasm. They contain virus particles, but they also have other constituents, and what makes these bodies form and adopt their varied shapes is unknown.

The spread of viruses

As viruses multiply only in living cells, their continued existence depends on their ability to infect a continuous supply of susceptible cells. A few viruses, of which tobacco mosaic is the foremost example, are stable enough to survive for long periods outside host cells, but most soon inactivate. In perennial plants or in plants propagated vegetatively, viruses exist safely for as long as these plants or clones remain viable, and such plants are often the sources of infection for plants raised annually from



Section through a potato leaf infected with potato virus X, showing large vacuolate inclusion bodies, many times as large as the nuclei.

PLATE IV

seed. However, a method of spread from one plant to another is essential, for not even perennial plants or clones live for ever. For their multiplication plant viruses depend on the synthetic capabilities of their hosts and equally for their spread from plant to plant they depend on the activities of living organisms. Uninjured plants are immune from infection; viruses enter plants only through wounds, and the wounds are made and viruses placed in them by a range of animals, of which man is not the least important. Not only has man distributed many viruses the world over by his traffic in living plants, but the horticulturist's technique of propagating by grafting might have been designed to spread viruses from plant to plant. Also, such practices as tying and disbudding a crop like the tomato spread tobacco mosaic virus through it very rapidly. This virus perhaps achieves the nearest to being able to spread independently, for when leaves of infective and healthy plants are rubbed together by the wind the virus may pass from one to the other through the wounds made.

The animals other than man that spread plant viruses are a varied lot, but the most important group are the insects, of which aphids, leaf-hoppers, thrips and white-fly, transmit between them more viruses than all other groups put together. Transmission is not a thing any insect can do; each virus is transmitted by one or a few related insect species and by no others. One aphid may transmit virus A but not B, whereas a second aphid may transmit virus B but not A.

The ways in which different viruses are transmitted differ greatly. Some viruses can be acquired by aphids feeding only briefly on an infected plant and then immediately be transmitted to a healthy plant, the whole process taking only a very few minutes; vectors of these kinds of viruses soon cease to be infective. Other viruses can be acquired only by vectors that feed for much longer on infected plants, and even after these vectors have acquired virus there is a delay of hours or days before they can infect a healthy plant. Some viruses of this type which are transmitted by leaf-hoppers multiply in their vectors; the delay between the time of acquiring virus and being able to transmit is presumably the time the virus takes to multiply and make the insect fully infective. The specificity of vectors for this type of virus is readily explicable by the need for the virus to multiply before it can be

transmitted, and this it does in a strictly limited number of species. Some insects become diseased when infected with this kind of virus, whereas most vectors are unaffected by the plant viruses they transmit. A few of the viruses that multiply in their insect vectors are also transmitted through the eggs to succeeding generations of insects, so that they can be perpetuated in a line of insects without each generation needing to feed on infected plants, but, as with seed-transmission in plants, this is unusual, and most insects start life free from plant viruses even though their parents carried them.

With viruses that do not multiply in their vectors, the delay between acquisition and transmission seems to be the time taken for the virus imbibed from plants to enter the gut, pass into the blood stream and reach the salivary glands, from where it is injected into plants on which the insects feed. Whether a leafhopper species can transmit a virus of this type may depend on whether its gut wall is permeable to the virus.

Those viruses that are acquired and transmitted within a few minutes clearly do not multiply in their vectors; nor is there time for the virus to circulate through the insect's blood stream. Transmission of these is by virus retained in the insect's mouth-parts, and what restricts transmission to specific vectors is unknown. The process at first sight seems to be simply mechanical, but some viruses, for example tobacco mosaic, which are the easiest to transmit by sticking pins first into infected and then into healthy leaves, are not transmitted by aphids that readily transmit other viruses, which are much more difficult to transmit mechanically.

Until recently the main small animals other than insects recognised as vectors of plant viruses were mites, but now some nematodes have also been incriminated. This promises to be a major discovery in explaining the spread and persistence of soil-borne viruses, the importance and prevalence of which are becoming increasingly recognised.

Knowledge about what viruses are and what they do has recently grown at an extraordinary pace, but it is still very far from complete. Of the much that has yet to be discovered, some will be helpful in decreasing the losses viruses now cause in crops, and some will be important to many subjects other than pathology, for it is likely to throw light on such general biological

processes as mutation, genetic continuity and the ways in which nucleic acid structure influences protein synthesis.

EXHIBITS IN THE LIBRARY

(*a*) A display of virus-infected plants, pictures and electron micrographs of viruses and their effects, arranged by *Mr. F. C. Bawden* and *Rothamsted Experimental Station.*

(*b*) Model of the hollow core of a virus particle and electron micrographs of tobacco mosaic and poliomyelitis viruses, arranged by *Birkbeck College Virus Research Group* (*The late Rosalind E. Franklin, A. Klug, J. T. Finch* and *K. C. Holmes*).

WHAT GOES ON INSIDE THE STARS

By H. BONDI, M.A., F.R.S.
Professor of Mathematics, King's College, London

Weekly Evening Meeting, Friday 6th November, 1959

Professor L. A. Jordan, C.B.E., D.Sc., F.R.I.C.
Vice-President, in the Chair

THERE are few parts of the universe that are as inaccessible to us as the interiors of the stars. However fanciful we may be in allowing for the achievements of modern technology and their future developments to take us to other parts of the solar system or even to some of the stars, we cannot imagine any possibility of ever entering their interiors. Nevertheless, there exists a coherent and successful theory of the structure of the stars. How does this come about? First, the observational evidence. The astronomer, by great refinement of his technique, is able to measure the distances of a quite considerable number of stars. Once knowing how bright a star looks to him, he can then work out how much light the star sends out by allowing for the usual weakening of the intensity of light with distance owing to its spread. In this way, he can work out for a considerable number of stars how much light they actually emit. This figure is known as the absolute luminosity. Next, he can look at the colour of the light received from the stars. This is done in a somewhat complex manner but results in a classification of stars as "red hot", "of yellow heat", "white hot", or "bluish white hot". As we know from terrestrial applications, and, indeed, from common experience, the colour of a glowing body indicates its temperature. A body only just hot enough to glow will emit dull red light; as its temperature is increased this will change to a bright red, then to a yellow, then to a white and, finally, although this is hardly possible in the laboratory, to a temperature so high that it shines with a bluish white colour. Moreover, it is well known in physics that the temperature of a glowing body not only determines the colour of the light it sends out but also how much light is sent out per unit area. The amount increases very steeply with the temperature; in fact, it goes with the fourth power of the temperature.

It is interesting that for a really opaque body—a black body as it is called technically—the colour of the light emitted and the

amount of light emitted per unit area depend only on the temperature and not in the least on the composition. Knowing, then, the colour of the star, one can infer the temperature of its surface which, in turn, determines the amount of light emitted per unit area of surface. Knowing also how much light the star emits altogether, we can by division find its surface area. Thus, although virtually every star looks like a pin point only, even in the telescope, it is nevertheless possible to determine the surface area and, hence, on the plausible assumption that the stars are spherical, the radius of the stars from measurements of the temperature. If a diagram is now drawn in which the absolute luminosity of the stars is plotted against the surface temperature, then it is found that the majority of the stars lies in a band stretching diagonally right across the diagram, from faint reddish stars, through medium bright yellowish ones, like our own sun, to very, very bright bluish white stars at the other end. All these stars are said to form the main sequence of stars. There are other groups of stars as well. There are some stars that are very luminous and yet very red of colour. Red colour means a relatively low surface temperature, hence very little emission of light per unit area. If the total luminosity of the star is high, it must hence have an enormous area, and such stars may be so large that if they were placed where the sun is, the orbit of the earth would be in the interior of the star. Such stars are known as Red Giant stars. Yet another type of star is distinguished by its low luminosity but nevertheless high surface temperature, the opposite in every respect of a Red Giant. Such a star is known as a White Dwarf.

In addition to the absolute luminosity and the colour, the astronomer can also determine the mass for some stars. This is due to the fact that stars very commonly occur in pairs, describing orbits about each other under the pull of each other's gravitational force. If the orbit of such double stars can be measured with sufficient accuracy, the attraction of each of the stars can be evaluated and, thus, its mass determined. However, masses are known for only relatively few stars, and are generally not known with the same accuracy as their luminosities or colours. It turns out that, for main sequence stars, the mass and their luminosity are very closely correlated. The larger the mass, the larger the luminosity. However, a relatively small increase in mass corres-

ponds to a very large increase in luminosity. Doubling the mass may multiply the amount radiated by a factor of 20 or so. Little is known about the masses of Red Giant stars; the masses of White Dwarfs are generally around the mass of the sun or a little less.

These, then, are the basic facts on which any theory of the structure of the stars will be calculated. The first step in any such theory is quite straightforward. Clearly, the huge mass of the star exerts an enormous gravitational force on itself which would tend to make the star contract rapidly. To counteract this enormous force, there must be another equally large one. Owing to their temperatures, the stars are evidently not solid, but liquid or gaseous, and the only thing that can hold a liquid or a gas from collapsing is a pressure gradient. We can, therefore, say immediately that the pressure gradient in a star must be sufficient to counteract gravity. In fact, these two forces must be in very exact balance. If in the sun the pressure gradient were only 1 per cent. less than that required to counteract gravitation, and remained so during the course of the contraction, then the sun would be collapsing completely in a matter of a few hours. The steadiness of the vast majority of stars thus proves that the pressure gradient very exactly counterbalances gravitation. The gravitational force depends on the distribution of density within the star and, thus, we have only one equation connecting two unknowns — the pressure and the density inside the star. We must somehow obtain a further equation so that the system becomes determined.

The first question then is whether the matter in the stars is gaseous or liquid. On the one hand, the enormous temperatures would lead one to believe that the matter was in the form of a gas; but the densities that occur (in the case of the sun, a central density a hundred times that of water) are so vastly greater than any that one knows for a gas, that this might make one think that the material would be in liquid form. However, Eddington's bold guess that it was gaseous has been completely justified by modern physics. We now know that, at these high temperatures, even at the densities prevailing in ordinary stars, matter behaves like a gas. A gas is a material in which there is a definite and simple relation between its pressure, its density and its temperature. Accordingly, our two unknowns—the pressure and the density—

now occur in another equation, but, unfortunately, in company with a new unknown—the temperature. We now have in fact two equations for three unknowns, and so we are still one short.

The next point is connected with the elementary fact that the stars shine; in other words, a current of energy flows constantly from the surface of the stars out into space. Assuming, as is eminently reasonable, that this energy current does not originate at the surface but well inside the stars, it follows that energy must be flowing outwards through the outer regions of a star. How does this happen? We know very well from daily experience that energy tends to flow down a temperature gradient. Energy moves from hot regions to cooler regions. However, the nature of this flow is slightly different in stars from what it is in our ordinary lives. We are most familiar with flow of energy by conduction. If you take a poker and hold its tip in the fire, the other end will in due course become hot. This is due to heat being conducted along the poker from the hot end to the cold one. Two other means of heat transport are convection and radiation. Convection and radiation are of particular importance in problems of domestic heating. A human being has a certain heat output which varies with activity. Sitting down, it amounts to about 100 watts; but when we take strenuous exercise, it may exceed a kilowatt. If one now sits in a room, how does one get rid of the 100 watts of heat one is producing? Part of it is given to the surrounding air. The heated air then rises and cold air comes down, a process that is due to the fact that that a heated gas has a lower density, that is, is lighter, than a cooler gas; and in this way some heat is removed from us by convection. Also, we sit in surroundings the temperature of which differs from our own body temperatures, and is generally much lower. We, therefore, radiate heat and these heat rays pass through the air, which is virtually transparent for them, until they hit the walls which absorb them. Of course, the walls radiate heat as well towards us. However, since the temperature of the walls is lower than the temperature of the human, we receive less from the walls than the walls receive from us. In other words, heat is transported by radiation from us to the walls. In ordinary circumstances, roughly half the loss of heat occurs by convection, and half by radiation. If the total loss becomes too large, we feel cold. To rectify this, heating is applied. It is, how-

ever, a fact that a much greater feeling of comfort occurs when we feel warmed by radiation, even with a large loss of heat to the air, than if we are in a warm atmosphere with cold walls. Thus, a room that has been cold for some days if suddenly heated so that the air is warm enough for us not to feel cold when we enter, will nevertheless feel uncomfortable and stuffy, for the walls, owing to their large mass, remain cold for some time, and so we suffer an excessive loss of heat by radiation, even though the loss to the air is reduced to a small amount. Real comfort conditions can occur only in a room that is heated all the time so that the walls take up quite a high temperature. As is well known, very comfortable conditions occur in snow and sun. Although the air temperature is very low, the sun's direct rays and their reflection from the snow, lead to a high radiation temperature. Thus, almost the whole heat loss is to the air which is the condition of extreme comfort and well being.

Very roughly speaking, the heat content that is affected by conduction is proportional to the temperature; but the radiated content is proportional to the fourth power of the temperature. Both these processes being of similar importance in our normal surroundings, it is clear that, at the very high temperatures of the stars, radiation is vastly more important than conduction. Convection occurs, but only in some rather special regions of the stars. (It is comparatively simple to formulate the conditions in which radiative transport of energy is augmented by convection.) We are now in a position to write down a third equation, namely, the equation for the flow of energy. How big has the temperature gradient in the star got to be in order that the correct amount of energy should leave the surface of the star? This third equation between our three unknowns – pressure, density and temperature – in addition to the equation of a state of a gas connecting the three variables, and the equation of pressure support, against gravitation is not quite such a simple straightforward equation as the others. The amount of temperature gradient required for a given transport of energy depends on how transparent or opaque the material of the star is. It is possible, with modern atomic theory, to work out the opacity of such material; but it is a difficult and rather awkward task and the result has some degree of uncertainty in it. Secondly, whereas, as we have

stated, a slight insufficiency of the pressure terms would show itself in a rapid collapse of the star, a slight unbalance in the energy transport equation would take millions of years to lead to observable results. Finally, although we have assumed that the energy comes from deep down in the star, we have not yet stated quite from how far down. Nevertheless, the three equations we have now are sufficient to describe the main features of the structure of the star provided only that we assume that the chemical composition of the star is the same throughout. It turns out that that the total outflow of heat from the surface of the star, that is, its luminosity, is controlled almost entirely by its mass, and depends very critically on the mass with a very minor effect of the radius. This so-called mass luminosity radius relation was the first great achievement of the theory of stellar structure and is in very good agreement with all that is known about main sequence stars.

If it is assumed that main sequence stars are of chemically uniform composition, consisting largely of hydrogen, then it turns out that, for such a star, the temperature at the centre is closely determined by the mass and the radius. Moreover, using the observational data, it emerges that the central temperatures vary only very slightly along the main sequence. Why should this be so? It is clearly a problem connected with the energy sources of the stars. Neither gravitational contraction nor any chemical reactions could have kept the sun shining for the enormous lengths of time for which evidence exists in the geological record. The only possible source of energy is then nuclear reactions occuring owing to the high temperature. Temperature determines the energy of the individual particles that make up the material. It is known that at sufficiently high velocities collisions between nuclei can lead to nuclear reactions. However, the velocities corresponding to the temperatures of the centres of the stars are very small by the standards of nuclear physics. This corresponds to the fact that the heat output of the stars per unit mass is rather small though, of course, the masses of the stars are so colossal that the total heat output is large. Thus, on an average, 500 tons of solar material are required to produce a heat output of 100 watts which, as I have been saying, is characteristic of a human at rest. Again, since nuclear reactions are so very power-

ful, it follows that only very rarely need a collision between nuclei in a star lead to an energy-producing nuclear reaction. On this basis, a nuclear physicist, using refined experiments and his theory, can work out what temperatures are required to meet the energy demands of the stars, and his calculations agree exceedingly well with the calculations of the astronomer for the central temperatures of the main sequence stars. The nuclear reaction responsible for the energy of the stars is the conversion of hydrogen into helium by one of two methods. The agreement between the temperature requirements is very close and is a real triumph of modern physics, for results from nuclear physics have to be fitted to results from astronomy in order to elucidate the conditions in the centres of the stars, and this work can be carried out with full consistency and perfect agreement between these very different branches of science.

While the theory of main sequence stars is thus in a very good state, we can also say something about the other classes of stars. First, the Red Giants. Since a main sequence star is homogeneous in its chemical composition, and since the nuclear reactions that produce its energy convert hydrogen into helium and depend strongly on the temperature, it follows that in the centres of these stars in the course of time helium will exist in considerable amounts, whereas none will be produced in the outer layers of these stars. Assuming, as we have very good reasons for doing, that the helium produced in the centre is not mixed around (essentially because it is heavier than hydrogen and thus will remain in the lowest position) it follows that a main sequence star will gradually become inhomogeneous with its centre helium rich and the outside still hydrogen rich. The time taken for this development is much shorter for big stars than for small ones, for, as has been said, the luminosity is a steep function of the mass. Thus, a star of twice the mass of the sun radiates maybe twenty times as much and, therefore, converts hydrogen into helium at twenty times the rate the sun does. It is true that its store of hydrogen is twice the store of hydrogen of the sun; but, even so, it will run through the same fraction of its hydrogen store in a tenth of the time. What will the effect of such an inhomogeneity be? This is a much more difficult theoretical question, but one can answer with a very great deal of confidence that it will lead to

a gradual enlargement of the star, to a swelling that gradually converts the star into a Red Giant. We can see now why Red Giants exist only amongst the brighter stars. The fainter ones simply have not yet had time to convert enough of the hydrogen into helium to lead to this characteristic swelling. We can compute from this the maximum ages of stars in our galaxy, and it turns out to be around ten thousand million years. A star as faint as the sun would need about three times this period before it could become a really immense Red Giant; whereas, for the much brighter stars this would occur sooner. However, the Red Giant stage can only be a period in the life of a really large star, for a Red Giant radiates enormous amounts. The energy for these can only be found by nuclear reactions. First, the conversion of hydrogen into helium, then some others which yield a little more energy. But before very long, the energy store of such a star must become exhausted. What will the star do then? It has to continue to radiate by the mass luminosity radius relation; but its energy sources have dried up and so it will begin to contract as it can no longer supply the necessary pressure. It will then go on contracting until one of two things happen. Either the originally slow rotation of the star will become so much speeded up by the contraction that some matter begins to fly off the surface. There is evidence that this occurs in some stars. However, other stars may have so little original rotation that this does not happen, or at least does not happen until the contraction has gone very far.

How far can the contraction go? A stage is eventually reached when the material ceases to behave like a gas. It does this in a very peculiar manner when the density begins to approach a quarter of a million times that of water. This is a truly enormous density at which the weight of a matchbox full of such matter would begin to be measured in tons. The peculiar thing about this situation is that the pressure is then no longer determined by density and temperature as in a gas, but depends on the density alone. In other words, the material has been as tightly compressed as it will go. A star that has reached this state is very much in a final state for, although the star will cool as more energy is radiated from its surface, this will no longer effect its structure. As its pressure depends only on its density, it can cool indefinitely

without changing in structure. In fact, such a star will cool exceedingly slowly for, owing to the high density, the surface is relatively small and so it radiates relatively little. Such a star is a White Dwarf. Gradually, as it cools, it becomes fainter and fainter and eventually reaches the purely hypothetical stage of being a Black Dwarf—an object that does not shine at all. However, it should be pointed out that, owing to the peculiar nature of the relation between pressure and density, this comfortable equilibrium can only be reached for stars whose mass is not much larger than that of the sun. No such final resting place exists for greater masses. In fact, we would suppose that only very massive stars can have burnt up enough of the nuclear fuel to have reached this stage of being a White Dwarf; but, in order to become a White Dwarf, they must somehow have reduced their masses. Thus, some kind of catastrophic or gentle break up is necessary in which material is expelled from these stars in order that they may reach the comfortable terminal position of becoming a White Dwarf star. Again the agreement with observation is good, as all the White Dwarfs that are known fall comfortably within the mass limit set by the theory.

EXHIBITS IN THE LIBRARY

(*a*) Diagrams illustrating distances, sizes and condensation of stars, heat and energy output, devised by *Prof. Bondi.*

(*b*) Model illustrating Stellar Parallax, lent by *The Royal Greenwich Observatory.*

(*c*) Photographs of stellar spectra, lent by *The Royal Astronomical Society.*

(*d*) Historical astronomical photographs from the *De La Rue Collection at the Royal Institution.*

PRISON: AN ADVENTURE IN PARADOX

By R. D. FAIRN
Director of Prison Administration

Weekly Evening Meeting, Friday 13th November, 1959

James Lawrie
Vice-President, in the Chair

I AM instructed that amongst the objects of this venerable Institution are "the diffusion of science and useful knowledge", and you must forgive me if I only just resist the temptation to speculate tonight upon the use to which you will put such knowledge as I may lay before you. My limits are set. We were told the other day that when the late Lord Cherwell, then Professor Lindemann, first arrived in Oxford, he was depressed at the low status accorded to science in that University and murmured his sorrow to the wife of the Warden of All Souls. She comforted him with the comment, "You need not worry, Professor Lindemann, my husband always says that any man who has got a First in Greats can get up science in a fortnight." Let us see how much prison we can get up in an hour. My first task must be to dispel the illusion about both detection and crime. Romance in detection is confined generally to the pages between the covers of the "whodunits". In practice, detection rarely consists of brilliant deductions conceived in an atmosphere of tobacco smoke: usually it involves something like the patient and dull examination of hundreds of pawn tickets in scores of shops. Similarly, crime is not often breaking into the Bank of England, it is much more likely to be the petty pilfering of milk bottles, bicycles and ladies' handbags. Let me add at this point that I range myself squarely with the Wolfenden Committee in their differentiation between crime and sin. I take sin to be what my friend, the late E. Roy Calvert called, "the conscious choosing of the lower of two moral alternatives". Crime, on the other hand is a social category and changes from day to day and from civilization to civilization.

What is the size of the problem? In 1958, in round figures, there were 990,000 offences dealt with in the courts. Sixty per cent. of these, or some 596,000, were traffic offences. Do I detect a certain criminal response in this audience? Indictable crime, that is

serious crime usually dealt with at Quarter Sessions or Assizes (the exception being those indictable offences triable summarily on consent) amounted to 147,000 offences, and 84 per cent. of these were made up of offences against property. Thirteen thousand, or 1.3 per cent. of the total number, were concerned with sex or violence. The impact of these total figures upon prison and borstal may be judged from a brief analysis of the daily average population housed in the Prison Commissioners' establishments at the present time. Tonight, as we are met here, there will be some 26,600 men and women, boys and girls in the prisons and borstals of England and Wales. About 1,200 men and 50 women will be there not necessarily because they have committed offences: they are unconvicted prisoners and held in custody against their trial. Three hundred and fifty men and a handful of women will be there as civil prisoners, debtors who have failed to pay, if they are men, wife maintenance or bastardy orders or, for both sexes, hire purchase or the like. Some 4,300 will be borstal boys and about 170 borstal girls, and the rest will consist of about 19,800 convicted men and 600 convicted women. You will note the disparity between men and women. Crime, to our discredit, is largely a male concern. I would give you one figure more. Tonight, some 6,400 men will be sleeping three in a cell in the local prisons in England and Wales, each cell measuring 13 ft. by 7 ft. by 9 ft., and I invite you to imagine what that means. I saw it the other morning in Oxford prison at 7 o'clock when prisoners were engaged in that ceremony accurately although not euphoniously called "slopping out". Such a denial of the basic needs of human dignity cannot be defended. It can only be explained against the rising tide of our prison population.

Now who are these men and women? If you and I were to visit the Reception in one of our large metropolitan prisons—one of my colleagues told me the other day that when he was at Birmingham, for example, 125 men passed in and out of that prison in 24 hours—who should we see? Housebreakers and shoplifters, 14-day drunks and false pretenders would be in the queue along with the occasional defaulting solicitor and pacifist idealist; here and there would be the sexually deviant schoolmaster or clergyman, the irresponsible and lazy husband or parent, the dishonest postman and even the aberrant scientist. And for the women we must

add as well the abortionist and the prostitute. Feckless often, greedy, dull, sometimes dangerous, often very ordinary, this procession reminds us that the unvoiced motto of the Prison Service must always be, "No destitute prisoner refused admission". Are they so very different from us? The curve of intelligence is the same as that for the general population. Lombroso's theories about a criminal type were long ago exploded, but let me add we owe him a great debt because he directed us to the study of the individual prisoner. Have they any factors in common? This is not the place to attempt to discuss the causes of crime, except that I must remind you that Lord Pakenham has only recently written a sizeable book to show how little we know about them. Nevertheless, I was interested in the findings of a prison discussion group at Wandsworth Prison recently. Assessing their own motivations, the men in this group came to the conclusion that when "starting on a job" their social age was about four and that when they resorted to violence if frustrated they regressed to the social age of two. The common factor in the make-up of most convicted law-breakers is that they have broken the eleventh commandment: they all thought that this time they would not be found out. I hope you will agree with me that we are dealing here not with a biological sub-class of the population. These men and women are bone of our bone and flesh of our flesh. We are dealing in prison and borstal with the problems of a common life in which we all share. Prisoners are people and people matter. William Temple, nineteen years ago at Lowdham Grange, reminded us of a simple truth. "No man," he said, "is a prisoner and nothing else."

These are the people who make up, day in and day out, our prison population. What of the prisons themselves? Though the profession of gaoler is, perhaps, the second oldest profession in the world, imprisonment as a punishment is, generally speaking, a relatively modern invention. The striking words still uttered at the opening of every Assize, that it is an Assize of "oyer and terminer and gaol delivery," remind us of the original function of the Judges on Assize. Prisons, which were controlled, outside the corporate towns, by the Justices of the Peace in Quarter Sessions, were for centuries places where persons were held, often in the most degrading and corrupting conditions, against their trial.

The Judge then arrived literally to "deliver the gaols". Death, transportation, physical punishment and the stocks were all methods of disposal. Is it tactless in these days to recall Johnson's remark to Boswell? "Sir, the Americans are a race of convicts who ought to be grateful for anything we allow them, short of hanging."

The revolt of the American Colonies and the refusal later of Australia to accept transported convicts, coupled with the growth of the humanitarian movement which led to the reduction of the number of capital offences, brought the central government into the gaol business. The convicts who would once have been hanged or transported had now to be housed, and the hulks and the penitentiaries at Dartmoor, Millbank and Pentonville were the immediate response. This double system of prison administration, the county gaols being under the Quarter Sessions and the convict establishments under the central government, was at last brought together in one system by the Prison Act of 1877 and it is from that Act that the present Prison Commission derives. Responsible to the Home Secretary but not a part of the Home Office, the Prison Commission has its own Vote in the House of Commons, presents an annual report to Parliament, it can sue and be sued and it can buy and sell land. It is one of the last examples of the 19th century ad hoc Boards, and is, so to speak, a vestigial relic. Parliament insisted on retaining the Commission in its present form during the discussion in 1948 on the Criminal Justice Bill chiefly, I suspect, because it did not want an anonymous division of the Home Office to exercise the powers at present residing in the Prison Commissioners over their charges. Parliament wanted, and I think they were right so to want, named individuals to be accountable. So my colleagues and I at this day control some 80 establishments, prisons, borstals and detention centres.

Against this brief exposition of the way in which the Prison Commission has come into being I want to discuss a certain confusion of purpose which concerns the exercise of the Commissioners' powers. Society asks, somewhat inarticulately, a great many things of its prison system simultaneously, and some are not always compatible with others. Any prison system must serve a custodial purpose. Safe custody is still, and I believe rightly, the first consideration of every prison officer. His is a

task which cannot be carried out by correspondence! There is secondly a coercive function, seen in the imprisonment of those who have failed to pay sums of money either by way of debts or fines. Thirdly, there is a deterrent function, by which society hopes the sentence the court imposes will stop the offender from repeating his offence and will deter others from following his example. Retribution, again, is a quite separate purpose and is felt often subconsciously. Many would go on to say that restitution ought to play an integral part in the right treatment of the offender. The late Margery Fry gave much thought towards the end of her life to devising ways by which reparation might be made to the criminal's victim. And at the end of all this comes Rule 6 of the Prison Rules, 1949: "The purposes of training and treatment of convicted prisoners shall be to establish in them the will to lead a good and useful life on discharge, and to fit them to do so".

In the middle of this confusion, I pose the inherent paradox of every prison administrator. The late Alec Paterson put it once and for all when he said, "You cannot train men for freedom in conditions of captivity." And yet this is precisely what every prison administrator has to try to do. Here is the paradox. How is it resolved?

I want now to touch on some growing points out of which, I hope, will emerge the adventure of my title. Let me at the outset direct you to the White Paper presented by the Home Secretary to Parliament in February this year, *Penal Practice in a Changing Society*. It is the first considered statement of penal policy in this country since the Gladstone Committee Report of 1895. At the conclusion of that Paper will be found four pages of research projects. Here is the first of my growing points. Belatedly, and only with Government financial aid made possible by the Criminal Justice Act of 1948, we are now using our own prison staffs, the Home Office Research Unit, the Universities and some specialist agencies on the fundamental business of research. We recognise that in social administration no less than in pure science and technology, further advance must be guided by the results of objective research. Present projects range from studies in sentencing policy and prediction to an interpretation of social life in prisons and borstals from the inside.

The century-and-more old prisons are still with us. And with them we carry a heavy inheritance of antagonism between prison staff and prisoner. Faced with this situation the Prison Commissioners initiated some years ago what is now called the Norwich system. This has spread to other smaller and medium sized prisons. In essence the system consists of a staff deployment by which effective continuity is achieved between prisoner and staff despite the court responsibilities of a local prison. At the same time care is taken to seek to relax certain points of tension. Prisoners are allowed to be out of their cells for meals and recreative association, and conversation in workshops is accepted so long as it does not interfere with industry or good order. Begun some three years ago, the Norwich experiment is still regarded as a piece of operational research.

Open prisons, though now in this country 23 years old, for the first one was begun outside the city of Wakefield in 1936, are no longer experimental, but manifestly remain a growing point. They still are one of the chief ways, for those prisoners suitable for open conditions, by which our essential paradox can be met.

As those who have seen the exhibition in the Library will know, radical plans have been worked out for prisons of new design, the first of which will be built at Blundeston in Suffolk. These plans have emerged from a joint Design and Development Committee made up of representatives of the Prison Commission, the Ministry of Works and the Treasury. The old prison hall, with its slate landings, will go. And along with it will go, we hope, the day of the large establishment. We think that from 300 to 450 or 500, at the most, is the limit beyond which a penal establishment should not grow. Another task of the same Committee is a design of a pilot remand and observation centre. The exhibition also includes some examples of prison work. You will notice that there is not a mailbag to be seen. Useful though that humble article is for the employment of short-term prisoners, it plays but a small part in the total industrial output of our establishments. Our great farms, the weaving shops, mat and tailors' shops, the foundries and the printing works, the carpentry and tinsmith shops, are balanced on the training side by a great range of vocational training, from radio mechanics and electrical maintenance at one end to building and painting and decorating at the other.

Many successes have been attained in the City and Guilds examinations.

In the evenings in the Commissioners' establishments some 1,500 classes are held each week, staffed chiefly by teachers supplied from the local education authorities, although some classes are taken by members of the prison staff. This educational enterprise, begun as a voluntary experiment 40 years ago is, I believe, a growing point of no small significance.

Perhaps the two most exciting developments of the last few years are first, the development of group discussions and inmate participation within the establishments, and second, the extension of pre-release hostels. The first is another example of our attempt to break the paradox, for these discussion groups are nothing less than the creation of an area of permissiveness within a necessary circumference of compulsion. Through them better relationships have become possible between staff and prisoners and by their means we hope that the attitudes of those who at present recidivate, that is, come back and back to prison, will wholly change. The second development, that of the hostels, allows prisoners, whilst still in custody, but during the last few months of their sentence, to work for full wages in the neighbourhood of the hostels and to find their feet again as responsible members of the community. Let me also add that they pay £2 7s. od. a week for their stay in prison! The effect of this opportunity on, for example, the men in Dartmoor has been to bring hope where once they had written themselves off.

A new Criminal Justice Bill, shortly to be published, will make provision for a unified treatment of the young offender and it will be found that we have there built on the experience of 50 years of borstal. We hope also to extend compulsory after-care to certain categories of other prisoners.

Two points remain for notice. The first is the characteristically British co-operation between Government and the voluntary agent. Members of our Visiting Committees and Boards of Visitors, the teachers, the voluntary visitor, all remain as essential elements of our system. I remember especially to-night my friend the late Gerard Hoffnung, the only professional jester to be a member of the Society of Friends who, as a voluntary prison visitor, used to take his great gift of laughter into the cells of

Pentonville. I believe this co-operation to be vital to any progressive administration.

My last point is perhaps the most significant of all. It is that of the recruitment, training and professional refreshment of our staffs. "It is men, not walls, which make a city". The Keeper of the Gaol, a phrase still used on some committal warrants, was an 18th century conception. To-day all our effort is directed towards the creation of a team who together shall form a therapeutic community.

Has the paradox been solved? The enduring purpose behind the work of the Prison Commissioners was stated once and for all 50 years ago by a great Home Secretary in Parliament in these words; "The mood and temper of the public with regard to the treatment of crime and criminals is one of the most unfailing tests of the civilisation of any country. A calm, dispassionate recognition of the rights of the accused, and even of the convicted, criminal against the State—a constant heart-searching by all charged with the duty of punishment—a desire and eagerness to rehabilitate in the world of industry those who have paid their due in the hard coinage of punishment: unfailing faith that there is a treasure, if you can only find it, in the heart of every man. These are the symbols which, in the treatment of crime and criminal, mark and measure the stored-up strength of a nation, and are sign and proof of the living virtue in it." But magnificent as Sir Winston Churchill's words are, I want the last words to come from a voluntary worker. They express for me the spirit in which alone our paradox can be resolved. They were written by Elizabeth Fry in 1827 when she was concerned with the visitation of women prisoners. Of that work she wrote: "Much depends on the spirit in which the worker enters upon her work. It must be in the spirit, not of judgment, but of mercy. She must not say in her heart 'I am more holy than thou', but must rather keep in perpetual remembrance that 'all have sinned and come short of the Glory of God'."

EXHIBITS IN THE LIBRARY

A display of scale models of Blundeston Security Prison; examples of work done by prisoners; illustrations depicting the objects of prisons; and photographs of drawings in Dickens' books illustrating prison life in the 19th century; arranged by *Mr. R. D. Fairn and H.M. Prison Service Staff College, Wakefield.*

ATOMS AND MOLECULES

By SIR LAWRENCE BRAGG, O.B.E., M.C., D.Sc., F.R.S.

Fullerian Professor of Chemistry;
Director, Davy Faraday Research Laboratory

Weekly Evening Meeting, Friday 20th November, 1959

W. E. Schall, B.Sc., F.Inst. P.
Treasurer and Vice-President, in the Chair

DURING the last six years a new scheme has been initiated in the Royal Institution which we term the "Schools Lectures". These lectures are given twice weekly from October to June, and are attended by boys and girls from about 500 grammar schools and other schools in which science is taught to an advanced level. Most of the lectures are for young people from the top science forms, but each year we have one series for younger boys and girls. It is hoped in this way to arouse an interest in science at a stage of their studies when they have not yet necessarily begun to specialise. The discourse this evening is one of these latter talks. I shall therefore ask the members of my audience to consider themselves as being 14 plus, and give this talk as it would be delivered to the young people, in the hope that it will be interesting as a sample of what we are are trying to do.

The main idea behind this particular talk is to make the boys and girls more familiar with the concepts of atoms and molecules. It is hardly possible to avoid using these concepts in any scientific talk, however popular. They do, however, present difficulties to the average listener who has no expert scientific knowledge. This is partly because atoms and molecules are so much smaller than anything which can be seen, and partly because the structure of an atom or molecule is so unlike that of any little piece of mechanism we can handle or visualise. The demonstrations were planned, therefore, to lessen the strangeness of this tiny world, by demonstrating large-scale effects which could be linked directly to the ultimate building particles of matter. The concepts are of basic importance.

An interesting thing one can tell the young people at the start is that our knowledge of the nature of atoms and the forces which

bind them together into molecules is so recent. The atomic theory was formulated by John Dalton a century and a half ago. He pictured the elements as being composed of identical small particles, the atoms. In compounds, the ultimate particles are in identical small groups of atoms called molecules, bound by forces of some kind into characteristic family parties. The molecule of water is always one atom of oxygen combined with two atoms of hydrogen, that of carbon dioxide two atoms of oxygen combined with one of carbon, and so forth. This postulate was based on the discovery that the relative proportions of elements by weight in a compound could be simply explained, by assigning relative weights to the atoms in it. Dalton's theory required no assumptions about the actual size or mass or structure of the atoms; it merely postulated their existence and their relative masses. When I was a young student, little more was known; atoms and molecules were still quite vague abstractions. In fact some well-known scientists still did not believe that their existence had been proved. All our intimate knowledge of them has been gained in the last fifty years.

The first step is to realize that their minuteness is not quite so terrifying as it might at first sight appear. The point is made with the help of a scale of sizes on a large diagram, each step in the scale being associated with objects ten times smaller in dimension than at the step above. The diagram is on a sheet of steel, and illustrations of objects on the steps can be clamped on by magnets as the argument proceeds. Experience has shown that this gives a more vivid impression than a ready-made diagram. The top step of the scale is associated with objects about an inch across, represented by large crystals of sugar which they can all see. Coffee-sugar crystals represent going down one step, they are about ten times as small; then comes castor sugar, then icing sugar, so we have gone down three steps of the scale in a painless way with quite familiar objects. The point to be made is that we only have to go down five more steps, and we shall have arrived at the molecules of which the sugar crystals are composed.

To see the form of the icing sugar grains, one must use a lens, and anything smaller requires a microscope. A microscope image of a flea represents an object seen in considerable detail, and one of a bacterium something which is already rather diffuse because

the microscope is nearly at its limit of resolution. Up to this point one is still in the range when "seeing is believing", but beyond it the difficult point is reached where things can no longer be seen with any optical aid. Starting with one inch one has gone down five steps to objects 100,000 times as small. It seems worth while explaining that light fails to be of any further help, because the details of the object are closer together than the wave-length of light. The object itself is not being magnified by the microscope, one is only magnifying a storm of light waves created when light falls on the object, and the details of this storm cannot be finer than the length of the waves which create it. A demonstration which seems to drive this point home is to sign one's name over about two feet, first with a crayon and then with a distemper brush. It is often hard to predict what success a demonstration will have; this particular one seems to tickle the fancies of the young people, it goes down surprisingly well!

The pictures obtained with the electron-micoscope serve to carry on the story. The very detailed picture of a bacterium, the bacteriophage, the virus are good examples. A virus particle can be claimed to be an extremely large molecule. An electron micrograph of a protein crystal shows molecules which are still very large, but now only about ten times as great each way as the sugar molecule. The electron-microscope pictures are so closely analagous to those obtained with an optical microscope that it is justifiable to claim this wonderful new instrument as one which enables us to "see" large molecules.

The final stage has to be touched on very lightly. So far it is only possible to deduce the arrangement of the atoms in the molecule by X-ray diffraction. One can show an X-ray diffraction photograph, preferably one with four-fold symmetry, and then ask the young people to look at a bright point source of light on the lecture bench through their handkerchiefs. The diffraction pattern produced by the handkerchief looks very like the X-ray pattern. It can be explained that they are produced in the same way, though the lattice pattern is due to waves 10,000 times shorter, and that the nature of the pattern can be deduced from the nature of the diffraction. The model of a sugar molecule which they are shown completes the story.

There are certain demonstrations of large-scale effects which,

to my mind, form a bridge between every-day experience and the minute world of atoms and molecules, and which show convincingly that matter is composed of discrete particles. The first of these is Lord Rayleigh's famous experiment which gave an approximate idea of the absolute size of a molecule. The young people often know something about surface tension, and one can do a few simple experiments to remind them that a liquid behaves as if it had an elastic skin, explaining that this effect is due to the pull exerted on the surface molecules towards the interior of the liquid. It is then pointed out that since the tension is a surface effect, its strength depends on the nature of the surface. If a drop of oil is placed on a water surface, it rapidly spreads as a thin film over the surface and the tension is reduced. Three sticks of wood can be laid on a clean water surface in a triangle, their ends adhering by capillary attraction. A drop of detergent, which spreads in the same way as oil, is allowed to fall inside the triangle, when the sticks fly apart with considerable velocity. This is a good example of the strength of the tension. Rayleigh used the camphor movements to indicate the area over which the drop spread. Particles of camphor scraped by a knife on to a clean water surface dash about in all directions, because the difference in tension of the camphor-contaminated water in their wakes behind them and the strong clean water surface in front to which they are drawn. An oil film kills the movement. Rayleigh guessed that the oil forms a monomolecular layer on the water, and by measuring the area over which a known amount of oil spread, he was able to establish that this layer is about 50 by 10^{-8} cm. thick.

Another piece of evidence is provided by the Brownian movements. Minute particles like those of smoke in air, or the fat droplets when a small amount of milk is added to water, are seen under a high-power microscope to be in constant agitation. Aquadag, which is a suspension of colloidal graphite, shows the effect well if a small quantity is added to water. The agitation is due to the bombardment of the particles by the molecules randomly striking them; they are sharing in the general kinetic energy of the molecules and if they are sufficiently small, the velocities are appreciable. One can illustrate the nature of the effect by making an artificial gas of a number of small ball-

bearings about one millimeter in diameter.* These are placed in a watch glass and magnetized by holding a strong permanent magnet beneath them. The glass is then placed within a Helmholtz coil, fed with 50 cycle current through a variac. As the current is increased, the bearings break away and roll about in all directions, because they each make a complete revolution in 1/50 second. A small wad of paper placed in their midst is knocked about in a way which simulates precisely the Brownian movement. This is a convincing way of showing that a gas cannot be a continuum, but must be composed of a number of particles flying about in all directions.

The crystalline state provides evidence that matter must be composed of particles. A pretty experiment devised by Professor Bernal explains the nature of a crystal. A number of marbles of uniform size, poured into a container of no special shape, make an irregular pile. If, however, one makes a container of four equilateral triangles, so that it has the shape of the lower half of an octahedron, and pours the marbles into it they arrange themselves regularly and pile up so as to complete a perfect octahedron, which can be compared with one of the octahedra so readily grown with alum. A crystal is a regular pattern of identical units, the molecules. If a piece of muscovite mica is cleaved, and a drop of ammonium iodide solution is allowed to dry out on the fresh surface, one gets tetrahedral crystals all pointing the same way, because the ammonium iodide fits itself to the underlying pattern of the mica surface just as the marbles crystallize in the regularly shaped container.

Finally, an attempt can be made to give the young people some idea of the nature of the forces which bind the atoms together into molecules. It can of course only be a very preliminary and general idea, which will become more precise as they pursue their scientific studies. The periodic table gives the clue. An atom cannot be compared to a tiny version of mechanical objects with which we are familiar, it is not a little solid joined to other atoms by hooks or bolts. It is like a small planetary system, with electrons whirling around a central nucleus, each atom in the ascending series of the periodic table having one more electron than its

*This delightful experiment was designed by Professor A. D. Moore, of the University of Michigan.

predecessor. The extreme change in chemical properties from one atom to the next, and the reappearance of similar properties in a periodic way, can only mean that the dance of the electrons around the nucleus is a formal measure governed by precise rules of symmetry, and not an irregular rout. One can compare the union of sodium with chlorine to a joining forces of two eightsome reel parties, one of which is short of a partner for the complete dance figure, and one of which has an extra wallflower who cannot take part in the dance. By sending a partner from one to the other, both parties achieve a more symmetrical state, which as in a crystal is the ideal form for the lowest energy state. This is of course only a pretaste of the more complete explanation they will get later, but the young people do seem to appreciate the conception, already illustrated by the crystal, that matter tends to take up its most symmetrical form and that atoms unite into molecules because, by exchanging or sharing electrons, they can build a neater structure of higher symmetry.

The purpose of these demonstration lectures is not to give the boys and girls information, but to give them concepts in terms of which they can think. They seem to remember so much better what they see than what they hear or read, hence all the emphasis is on experiments, working models, or attractive diagrams. We are indebted for help in planning the lectures to the science teachers, who advise us as to how we can best supplement what the young people learn at school.

EXHIBITS IN THE LIBRARY

A display of school teaching apparatus purchased from grants given to the R.I. by *Shell International Petroleum Co., Ltd.* and *Imperial Chemical Industries, Ltd.*

Demonstration apparatus given by *Bell Telephone Laboratories, Inc.*

THE SCIENTIFIC LESSONS OF INTERROGATION

By ALEXANDER KENNEDY, M.D., B.S., F.R.C.P., F.R.C.P.E., F.B.Ps.S.
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Weekly Evening Meeting, Friday, 26th February, 1960

W. E. Schall, B.Sc., F.Inst.P.
Treasurer and Vice-President, in the Chair

IN studying the effects of stress on body and mind two kinds of evidence have to be considered, that which is objective and measureable and that which depends on the personal account given by the subject. The latter is available only in man and the extent to which the human subject can be subjected to extremes of stress in experimental conditions are necessarily limited. One must, therefore, like the cosmologist, wait upon such experiments as nature and circumstance see fit to provide. War and occasional major physical disasters have provided unique opportunities where large numbers of individuals have been exposed to the same stress in conditions which have rivalled those of laboratory experiment in their simplicity and rigour. This discourse is based on the recorded observations which have been made on a relatively small number of individuals exposed to a highly specialised form of stress, that of detailed interrogation having as its object the transfer of loyalties. The emphasis throughout will be placed on those results for which applications have since been found either in the further scientific investigation of stress or in the treatment of psychiatric illness.

INQUISITION AND WAR

The history of major conquest shows that defeat in battle alone does not often change the heart of an enemy and that it may even render the transfer of his loyalties more difficult. If wars are to continue, the future choice for those who initiate them would seem to be between making an uninhabited desert of the enemy's country and calling it peace, or embarking on the dangerous uncertainties of total psychological warfare, for as will be seen, survivable physical offence merely gives coherence to the psychological defences of both individual and group.

On the sidelines of war of whatever temperature an agent or a key political figure of one power inevitably falls from time to time into the hands of another. He may be interrogated in the hope that the information he bears will be of value, but his greatest importance in the eyes of some ideological groups lies in his potential use as a weapon of offence. If he can be made sincerely to change his loyalties, he can be used to give false information to his sponsors, or he can give public testimony of his change of heart and his former deviation from what he now knows to be the right. From the history of the Inquisition we learn that certain empirical discoveries were made and recognised as important by a thoughtful and objective minority of those concerned. The first was that if a prisoner were once induced to give a detailed history of his past and to discuss it with his interrogators in the absence of threat or persuasion or even of evidence of interest, he might after an emotional crisis recant and confess his heresies. The second discovery was that true and lasting conversion could never be produced by the threat of physical torture. Torture not infrequently had the opposite effect and induced a negative mental state in which the prisoner could no longer feel pain but could achieve an attitude of mental detachment from his circumstances and with it an immunity to inquisition. The most surprising feature was the genuine enthusiasm of those who did recant. While these results were necessarily ascribed at the time to the powers of persuasion of the Inquistadores, it is evident in retrospect that something was happening which was often beyond their control. The same facts come to light in the long history of Russian political interrogation. In the Leninist period, the success of the immensely tedious method of didactic interrogation then in use was similarly ascribed to the appeal of Marxist doctrine to reason. The fact is that in conditions of confinement, detailed history-taking without reference to incriminating topics and the forming of a personal relationship with an interrogator who subscribes to a system of political or religious explanation, there may occur an endogenous and not always predictable process of conversion to the ideas and beliefs of the interrogator. Further confirmation of this principle comes from the classical technique of psychoanalysis where the aim is to explore the analysand's past in conditions of minimal distrac-

tion so as to review and to revise basic attitudes acquired in his early years. The usual result is that, if he persists beyond a certain point, the patient becomes an enthusiastic convert to the dogma of the psychoanalytic school to which his analyst belongs. The comparison with both religious and political conversion and instruction is inescapable.

In the presence of evidence of this sort, it is for science to observe what has happened while keeping an open mind about the explanation, to look for further examples of the same process in other settings and to seek ways of making the process predictable. Opportunities have arisen in circumstances where it is thought an urgent matter to interrogate certain types of war-detainee in minimum time and to induce in them a state of conversion which can be exploited in the interests of those who have detained them. The published literature on this subject is now extensive and it is possible from it to piece together the principles of the method and its results including the subjective effects on those submitted to it.

SOURCES OF THE TECHNIQUE

Since this discourse is concerned with information derived from the methods used rather than with the method itself, it will suffice to summarize briefly its origins and the principles which underly its use. The main principles were derived from the following sources:

(1) Existing knowledge of the physiology of consciousness, and the psychological effects of sensory deprivation.

(2) The theory and technique of Conditioned Reflexes as applied to the conditioning of the physical concomitants of emotion in man and the induction of artificial neuroses.

(3) Psychological study of the psychological mechanisms seen in human beings under acute stress and in conditions of mental conflict and of the interpersonal relations and emotional transferences encountered in the course of psychotherapy and religious conversion.

(4) The empirical and largely personal methods of experienced and successful interrogators such as those of the Inquisition and of those armies which subject prisoners of war to detailed interrogation.

ESSENTIALS OF THE METHOD

Although the steps by which results are achieved are remarkably uniform when the wide variations in human personality are considered, detail has necessarily to be varied or eliminated and the method adapted to different subjects and circumstances. The following summary compiled from a variety of sources is therefore necessarily simplified and standardised. The division into stages is largely artificial as the management of each individual is a continuous process.

I. *Disorientation and Disillusion*

Induction of disorientation as to time and place by the use of conditions of partial sensory deprivation and by subjecting the subject to confusing stimuli. Production of uncertainty as to contact with environment, personal identity and basic social orientation. Causing doubt as to the existence of values such as right or wrong, to which the interrogator shows complete indifference. Creation, based on the foregoing, of a state of insecurity as to the dividing line between the thoughts of the detainee and those of his interrogator. The avoidance of negative or inhibitory states is essential at this stage and is achieved by showing no positive response to anything said and ignoring all questions.

II. Synthetic Conflict and Tension

Production by conditioning methods of a state of psychological tension with its concomitant physical changes in heart, respiration, skin and other organs, the feeling being unattached to any particular set of ideas. This is later caused to transfer itself to synthetic mental conflicts created out of circumstances chosen from the subject's life-history, but entirely irrelevant to the reasons for his detention. The object is to build up anxiety to the limits of tolerance so as to invoke pathological mental mechanisms of escape comparable to those of Conversion Hysteria.

III. Crisis and Conversion

At this point the subject is without any system of reference by which to guide his attitudes or solve his conflict. He is concerned only with his own limited present. Without

any attempt at persuasion, it is indicated largely by implication that a way of life and thought exists which will provide a stable, even if false, basis for existence and will give relief of tension by its acceptance. The subject is tempted to achieve peace of mind and relief from his "abstract" anxiety by a change of orientation and acceptance of an idealised, dogmatic frame of reference. This is now made easier by his belief in the power of the interrogator to know the content of his thoughts and even his dreams. Following a state of doubt and conflict an emotional conversion-crisis is then induced. A sense of quiet and a desire to make up for bad thoughts in the past are now allowed to appear (i.e. they are not ignored by the interrogator who shows personal sympathy). Acceptance of the new doctrine, as soon as it has occurred, is immediately rationalised by a token act of treason on the part of the subject (e.g. recording his new beliefs for broadcasting or denouncing a colleague) so that he is now irrevocably committed to an act of treason for which he has no insight.

IV. Rationalisation and Indoctrination

Detailed analysis of the past is now undertaken in the light of the newly accepted system of reference. The subject realises his errors or deviations for which he feels a sense of guilt and a desire for atonement. Guidance is available from an interrogator with whom a friendly but dependent relationship has been formed. The detainee is glad to accept a humble status within revised loyalties. He is given adequate rest conditions amounting to convalescence and healthy occupation.

V. Apologetics and Exploitation

An introspective search is now carried out for ways in which the subject's knowledge of the enemy's activities can be used to further the aims of the system, now invested in his mind with qualities of reasonableness and justice. He is integrated into a limited community already loyal (i.e. interrogated) to the induced credo with ceremonial and symbolic acts of acceptance within it which stir him deeply. His re-education and training is carried out in a group of similar subjects who voluntarily police each other, jealous of their new-found loyalties.

OBSERVATIONS DERIVED FROM THE METHOD

The unique experimental neurosis created during these interrogations and such opportunities as have occurred of observing physical variables and recording the subjective responses of subjects has produced valuable information. It has also suggested further experiments which can be made in entirely humane circumstances. It has cleared the ground for a re-examination of the psychology and physiology of consciousness and has obvious applications to the treatment of psychiatric disorder. The rest of the discourse will be devoted to these applications. The broader fields from which the technique has been drawn and to which its results have contributed are here represented diagrammatically (Fig. 1.)

SOME APPLICATIONS OF THE PRINCIPLES OF INTERROGATION

A general account can now be given of some of the fields in which information gained from the method has been applied in Medical and Psychological treatment.

I. THE INGREDIENTS OF CONSCIOUSNESS AND THE TREATMENT OF DELIRIUM

In conditions of solitary confinement prisoners soon become aware of the need to orient their thoughts about temporal landmarks such as the arrival of food, the cycle of day and night and the regular routine of the prison. Where they are kept in the dark and are visited irregularly they realize sooner or later the danger of allowing themselves to drift into a state in which awareness of the passage of time is lost. They may feel impelled to occupy themselves mentally by a fear of losing control. If they are in a silent room the walls of which do not reflect sound, in darkness or dimly lit, and food is brought at randomised intervals by uniformly dressed individuals who make no comment, orientation in time is inevitably lost. Further, if the individual, on his arrest, is given no explanations and no information about the identity of his captors and if he is at once made unconscious and only awakened when he has been put into a 'neutral' room, the process is greatly accelerated. If he is exposed to confusing sounds in the first few hours his

THE SCIENTIFIC LESSONS OF INTERROGATION

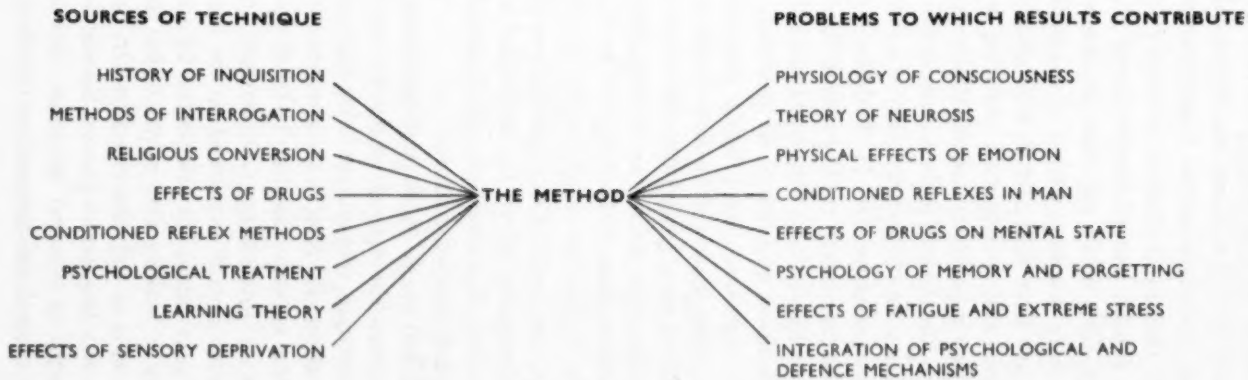


FIG. 1.

doubt as to where he is is increased so that orientation in place and in his relationship to those into whose hands he has fallen becomes very uncertain indeed. Experiments with volunteers have shown that in conditions of nearly complete sensory deprivation a total loss of consciousness will occur usually within forty-eight hours and that on restoration of normal conditions there is a long period of confusion in which the individual may have difficulty in distinguishing between his own thoughts and information reaching him through his senses. He may experience hallucinations and make mistakes in perception like those of patients in delirium. Recently, while we were waiting on the construction of a sensory deprivation chamber, my colleague Dr. H. Bethune suggested that we might, for the time being, try to produce the effects of sensory deprivation by hypnotising volunteers and inducing functional blindness, deafness and loss of all sensation. This was done successfully, communication being maintained only by a system of tapping signals on an area of skin on one wrist. The effects produced were remarkably like those of complete sensory deprivation, the patient on arousal after eighteen hours being in a severe state of confusion. The indications, therefore, are that hypnotism which, of course, induces no structural change, can produce a temporary loss of function of the nervous pathways by which the individual is in contact with his surroundings. The electroencephalographic tracings at this time resembled those of delirium.

From this and the evidence from pathological lesions which have interrupted the sensory pathways reaching the central regions of the brain, it seems probable that consciousness cannot be maintained for long in the absence of a sensory intake. Consciousness appears therefore to be an epiphenomenon of the process of integrating new sensory impressions with memory-traces already imprinted on the nervous apparatus. A prisoner may retain his orientation by forcing himself to recite poetry or making inventories of his possessions or his knowledge, as is so well described by Dr. Edith Bone in her experiences in a Hungarian prison. Sooner or later, however, in the absence of external stimulus, disorientation occurs and with it a condition resembling delirium which, as con-

THE INGREDIENTS OF CONSCIOUSNESS

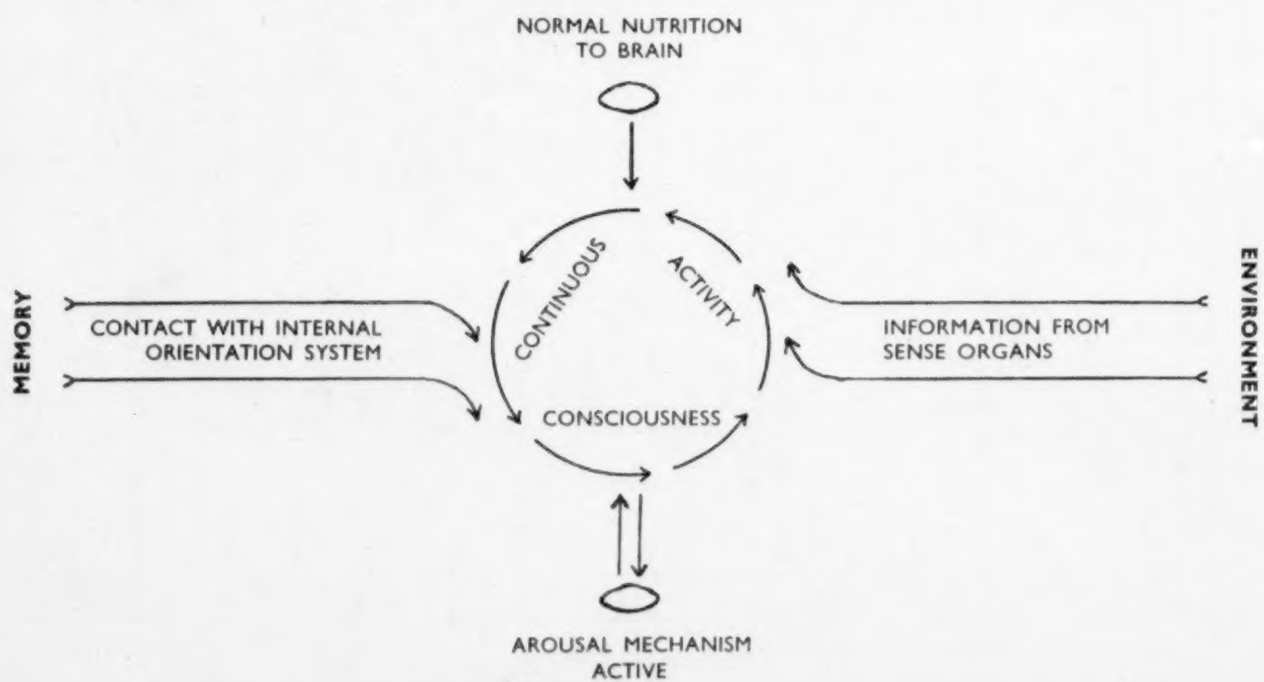


FIG. 2.

sciousness is quantitively reduced, has a most unpleasant emotional tone of fear and uncertainty. The ingredients of consciousness may be represented diagrammatically (Fig. 2). From this it will be seen that consciousness is relative. Complete sensory deprivation is not necessary to produce the effects described. When the level of consciousness is low, fatigue or very small amounts of drugs will produce hallucinatory experiences, especially if ambiguous sounds and unstructured visual stimuli are presented to the subject. These he will misinterpret through errors of perception due to the combined effects of the drug and his own reduced state of consciousness.

The resemblance of the effects of this induced disorientation to the delirium so often seen in the aged is very striking. In 1948 with the late Dr. Oscar Olbrich I was faced with the problem of treating attacks of acute confusion in aged patients who were being admitted to a psychiatric observation ward in Newcastle-upon-Tyne and a geriatric unit in Sunderland. Many of these patients, before their admission to hospital, had been living alone in dingy rooms, rarely visited by the younger generation and were suffering from the effects of inertia and self-neglect. Many of them had poor sight and hearing and had little initiative to go out shopping or to maintain contact with relatives and friends so that they were in fact in a state of partial sensory deprivation. When we began, our treatment consisted mainly of the elimination of toxic illness and nutritional defects. It was fairly successful, but it was soon evident that improvement took place much more quickly in some wards than in others. Physical disease apart, it became evident that the extent to which these patients made contact with the nurses and were treated as individuals had a considerable influence on their speed of recovery. Further, if on recovery their beds were moved so that they faced in a different direction or even if they lost their spectacles, they might relapse completely. The importance of orientation in general thus became clear as well as the particular effect of disorientation in time in increasing spatial and personal disorientation. Delirium may thus be brought about by the cumulative effect of partial disorientations in a brain working in conditions of poor nutrition.

From this and similar observations has been developed in the last ten years a system of nursing delirium in which there is an emphasis on orientation in time and place, recognition of familiar objects and faces, illumination at night, minimal changes of staff and breaking down of the impersonality so common in hospital life. Gradual improvement in the technique with the aid of a highly conscientious team of nurses and doctors has justified the recent setting up of a special delirium ward in Edinburgh. It is decorated in colours which, as seen through the aged eye, help the patient to get his bearings. Curtains and walls are free of designs likely to be misinterpreted in a state of reduced consciousness. The results are striking not only in the speed of recovery to a reasonable level of mental health but in mortality itself, for death from exhaustion due to restless delirium was quite frequent before present methods of treating senile confusion were adopted. It is true that much of the improvement has also been due to new methods of regulating the metabolic chemistry of the aged, but there is no doubt about the importance of surroundings and of a nursing team aware of the paramount importance of orientation. Needless to say, awareness of the orientation factor in the causation of this type of illness can lead to its earlier recognition in the patient's homes and prevention, by means of social services designed to eliminate the conditions in which senile delirium develops.

II. PHYSICAL ORIENTATION AND ITS RELATION TO ETHICAL AND MORAL VALUES

It has been a matter for surprise that after interrogation individuals with the strictest principles have abandoned and betrayed them without appearance of guilt or distress. A possible explanation lies in the supposition that moral values and principles of conduct are a form of orientation in the relationship of the individual to his civilised environment. In any act of recall there are two factors, the material to be recalled and the framework of associations with which it becomes linked in the act of making the initial memory-trace. Where a course of conduct is under consideration, it is recalled in relation to general principles by which behaviour is guided, principles

learned in earlier life. In interrogation the aim is not so much to extinguish memory but to destroy the systems of reference by which events or ideas are remembered. When the biological clock has also been rendered useless and disorientation in time results, spatial orientation in relation to the individual's own built-in body schema and world-schema is the more easily lost so that there is eventually a loss of the sense of personal identity. By the time the individual has thus become almost *tabula rasa* he is also unable to refer to his former ethical principles, so that for the time being he becomes a palimpsest upon which new and artificial values can readily be inscribed by an interrogator towards whom the subject has positive feelings. I have shown elsewhere that the integrity of certain nervous pathways is essential for the existence of ethical valuation so that a kind of moral unconsciousness or unawareness appears when they are destroyed by disease. A hypothesis of this kind may possibly explain the ethical inconsistencies which are so much in evidence after the crisis of interrogation or, for that matter, after conversion-crises in religious or political belief. There are now, for instance, a number of accounts of conversions from Communism to Christianity which have resulted in the betrayal of Communist groups to which the convert formerly belonged. These betrayals, for such they are in whatever direction the conversion may be, are accomplished without any sense of guilt and indeed with every semblance or righteousness. There is every reason to believe that the conversion could be reversed in the hands of Communist interrogators.

While these observations make no very direct contribution to the problem of human responsibility they do point out the necessity for presenting to each individual in the course of his development, a clear orientation in the principles of conduct which is neither too naive as to be implausible nor too abstract as to be unintelligible so that it will persist even in conditions in which his relation to the rest of society are in doubt or in which an inefficient brain weakens his orientation in general. Severe delinquent behaviour in the 8-14 age-group, the age in which social responsibility is being learned, is often related to brain disease, while in those whose first offences are in

adolescence it is more often associated with conflicting codes and uncertain personal relationships. Perhaps a simple code is better than no code at all. The status of moral values in a hierarchy of orientations is here suggested in diagramatic form:

SOME TYPES OF ORIENTATION

Type	*Reference Scheme*	*Effect of Loss*
Temporal	Biological rhythms. Memory of consecutive events	Disorientation in time
Spatial	Body-scheme World-scheme Geographical memory	Disorientation in space
Psychomotor	Innate and stored action-patterns and rhythms	Clumsiness, loss of initiative, inappropriate and disordered movement
Personal relations	Self and non-self Recollection of persons	Unreality feelings Mistaken identities
Attitudes and loyalties	Memory of previous attitudes to persons and ideals	Unstable attitude to persons and circumstances
Values	Acquired sense of values Acquired behaviour patterns Comprehension of feelings of others Foresight of effects of behaviour	Amoral outlook Loss of sympathy Impermanence of loyalties Unpredictability and perplexity

III. APPLICATIONS TO THE THEORY AND TREATMENT OF NEUROSIS

Neurosis is a manifestation of failure on the part of an individual to adapt efficiently to his circumstances. In all neurosis evidence of past or present anxiety can be elicited. It has been generated by fear, frustration or mental conflict

arising within the individual and from the interaction between him and his environment. In interrogation, anxiety is produced artificially and brought to the point where an artificial neurosis has been installed and this is then treated in a way which allows of the formation of a personal relationship with the interrogator and an acceptance of his ideology. Experimental neurosis in animals and its treatment has already taught us a great deal about the physical concomitants of anxiety, and the action of the heart, capillary blood-vessels, respiration, fluid-balance, nervous excitability and response to conditioning stimuli can be measured objectively. There was no means, however, of correlating these changes with the feelings and attitudes of the subject. Such measurements as have been made during interrogation are a step in that direction. The working hypotheses or psychodynamic theories at present used by most psychiatrists in the treatment of neurosis have been derived from psychoanalysis, and as there are many theories there is a serious need to check them against objective results. In some respects the results of the method confirm some of this theoretical framework while in others they have pointed out what may be fundamental errors. Some examples will be given of the light thrown on some widely held beliefs which are used as a basis for psychological treatment but which are difficult to subject to experimental proof. That the results of psychoanalysis are very difficult to submit to statistical scrutiny is generally agreed so that any reliable check on its basic tenets is to be welcomed.

(a) *The non-specific effects of treatment of conflict and anxiety*

Some of the individuals subjected to the method have given a history of previous psychological maladjustment so that their choice of work as an agent or saboteur may have resulted from a sense of failure in work or marriage which in this way they were hoping to escape. The recovery of their mental health after the treatment of an artificial neurosis has suggested that treatment of the anxiety due to artificial conflict may have had a beneficial effect on that arising from a real one. It is within the experience of most psychotherapists that a patient may recover following the development of insight into a mental

conflict and that it may come to light subsequently that a much more serious conflict existed which was not even discussed. These results point to the same conclusion. The fact that patients with similar neuroses can recover after treatment based on a variety of theories, all of which cannot be correct in the absolute sense, suggests that the manipulation of anxiety in general in the treatment situation may sometimes be much more important than any insight the patient may gain into the chain of causation of his neurosis. The traditional emphasis on insight in psychotherapy may in fact be misplaced and man may be an even less rational animal than psychoanalysis has suggested.

(b) *Place of Catharsis in treatment*

The outpouring of emotion in relation to the recall of painful past experience was an important part of early psychological treatment, since it was usually followed by improvement in the patients' symptoms. In the so-called abreactive methods of treatment, it still occupies a central place and a great deal of psychotherapy still consists of "working through" and "acting out" emotionally charged situations in the patient's past. For the tension induced in the course of inquisition, catharsis or the outpouring of emotion associated with confession, gives only temporary relief and then only if the subject is allowed to produce new facts. It does not appear to make any permanent contribution to the resolution of the neurosis, but acts as a sort of safety-valve when tension is intolerable. The urge to vent emotion is increased by indifference on the part of the interrogator or psychotherapist. It can thus be exploited by converting it into an urge to confess so that its main value in treatment seems to be to elicit more information. Catharsis therefore is a useful expedient but the use made of it as an end in itself in psychotherapy is not supported by the results in artificial neurosis.

(c) *The Freudian Theory of Dreams*

Freud regarded the study of dreams as the most important clue to the general trend of unconscious thought. He postulated that the dream was a loosely woven succession of

thoughts made up from events from the previous day, the effects of sounds or feelings appreciated during light sleep and the emotions derived from instinctual drives and buried conflicts which usually appeared in a disguised and symbolic form. These disguises enabled the dreamer to protect himself from waking up as a result of his thoughts and of outside stimuli. While this may be a simplified statement of the theory of dreams, information derived from interrogation appears to support it in every detail.

In the course of detailed interrogation the subject necessarily becomes fatigued, but deep sleep may be prevented by stimulation, by refusing to let the subject remain in a comfortable position or close his eyes, or by the use of such drugs as thyroxine or amphetamine. When he is in light sleep noises may be made, the interpretation of which by the prisoner is fairly predictable when the interrogator is aware of the full content of the previous day's discussion. In this way the interrogator soon has a good idea of the content of the prisoner's dreams so that he can on the following day refer to them as something known to both. The purpose of this device is not only to destroy the distinction between uncontrolled dreaming and waking thought, but also that between the thoughts of the interrogator and of his prisoner in the mind of the latter. This accelerates the process of destruction of personal identity. The fact that it works indicates that Freud's assumptions based on his own and other people's dreams are reasonable and the use of guiding stimuli in light sleep has already been tried on volunteers and in the treatment of neurosis. Freud's theories were mainly derived from the interpretation of dreams with a sexual content and they now receive confirmation from dreams in which the tension was derived from a very different type of stress. While a wholly sexual theory of human neurosis is now held only by a few psychoanalysts, these results show that the aetiology of similar states can be wholly non-sexual.

(d) *The Conditioning of emotional states*

By studying physical variables such as the pulse rate and skin resistance during interrogation, it is possible to find questions which regularly elicit an anxiety-response. This is

the principle of some of the "lie detector" methods. By associating these responses with stimuli such as musical notes or the movement of a revolving disc with sectors in different colours, it becomes possible to reproduce the physical effects of anxiety by giving the stimulus in the absence of a question. The presence of these physical changes produces a feeling of anxiety which can thus be generated in relation to innocuous questions or to the discussion of conflicts quite irrelevant to the interrogation. The most striking feature is the small number of trials necessary to install the abnormal response, when the process is compared with the results of human conditioning experiments in the absence of emotion. From this may be derived the general principle—*that conditioned responses are installed in man after a minimal number of trials in circumstances where attention is maximal due to the presence of anxiety or fear*. This has important implications for psychopathology. It may further be concluded that a most important factor is the interest or indifference of the interrogator at the time answers are given to questions, so that the use of positive or negative attitudes is a most useful method of furthering the interrogation. Just as a prisoner kept in complete darkness will sometimes shout out unsolicited confessions, so indifference to facts will elicit more facts and a positive or negative attitude in the course of treatment may determine whether the patient comes forward with information or retreats into a negative or inhibitory state.

(e) *Negative or denial reactions*

The infliction of pain, exhibitions of anger or the threat of torture or death have long been known to lead to a state of indifference to the efforts of interrogators associated with anaesthesia to inflicted pain and a sense of calm. While the serenity of the prisoner has often been attributed to a spiritual enlightenment, it seems for practical purposes to be comparable to the "Belle Indifference" seen in the subjects of conversion hysteria. It also has features in common with states induced by hypnotism. As in some hypnotic states and in hysteria of recent onset, the subject, so far from being suggestible, does not react at all and the same applies to the detainee

who has gone into a negative or inhibitory state. After a conversion crisis, however, suggestibility is maximal and almost any doctrine is acceptable. Moreover, the subjects may spontaneously pass into amnesic fugues in every way comparable to those of hysteria. On this basis, the induction of both an inhibitory state and a suggestible state in the course of interrogation would suggest that there may be two types of hysteria, a purely inhibitory denial reaction and a state which follows the crisis of conversion in which suggestibility is maximal. This would indicate that Pavlov's observations on dogs in the conditioning chamber are, so far as hysteria is concerned, nearer to the realities of human neurosis than the theoretical framework derived from psychoanalysis.

(f) *The effects of Traumatic psychological experiences*

A fundamental feature of psychoanalytically-oriented theories of neurosis is that adverse psychological experience is thought to leave an almost indelible effect on subsequent attitudes. Although they are inflicted on the mature and not the developing mind, the experiences of the interrogated are nothing if not traumatic. Considerable interest therefore attaches to the long-term effects of the experience both from the point of view of neurosis in later life and also that of the permanence of doctrines accepted as the result of exposure to the method. The examination after a long interval of a small number of subjects has given an indication of its long-term effects. In these the missionary zeal for the new cause had died down and had been replaced by a notable tolerance of the doctrinal excesses of others rather comparable to that seen in the prisoners of the Japanese who had survived their experience without a break in morale. Nightmares and fears had long subsided and all commented on the fact that they were in some respects the better for the experience. There was an initial unwillingness to recall the experience but this repressive tendency seemed to be confined to the constellation of ideas which included capture, interrogation and the subsequent acts of treason. It was, however, possible to promote quite full recall although the distinction between thought and actual experience was blurred and the experiences had a dream-

like quality and were clearly distorted, certain incidents standing out clearly. It was notable how little ill-will was borne against those who carried out the process. There was some resemblance to the introspective objectivity of the individual who has emerged successfully from a training psychoanalysis. In others in whom detailed interrogation had clearly not been brought to the point of crisis because a treasonable bargain had been struck with their captors at an earlier stage, the effects were quite different, the prisoner's subsequent life containing many instances of rationalising his treason, including the writing of books and newspaper articles. Some of these have undergone religious conversion in a way which suggests that they finished off voluntarily what their interrogators found at the time to be unnecessary. The results of the limited evidence available so far suggests that the permanent effects of interrogation may not be adverse provided that it is complete, and that the human mind has greater powers of spontaneous recovery than has been thought. One of the results of the statistical follow-up studies of psychoanalysis in recent years has also been to draw attention to the fact that the untreated cases of neurosis who acted as controls had a much better outlook than was thought possible.

(g) *Psychosomatic changes and the Biological Clock*

A striking feature of artifically induced confusion is the way in which disorientation in time accelerates the whole process. It suggests that, apart from a continuous sensory intake, *a time-base may be necessary for human mental operations.* It is difficult to imagine any kind of rhythmic, consecutive or periodic operation without some sort of time-marker and there are indications that in certain diseases of the nervous system characterised by disorderly movement and tremors of constant frequency, that some such mechanism has gone wrong. Physical changes which have a diurnal rhythm become disordered if this is changed, for instance, by air journeys through the different time-zones. So far as longer periods are concerened, there are phases in some diseases which suggest not only a menstrual but a seasonal cycle so that there are probably both neural and glandular sequences of activity which serve as

time-markers. The disordered timing of prolonged confinement in conditions of partial sensory deprivation provides an opportunity to learn about these mechanisms by finding out what happens if their normal operation is disturbed.

An examination of the immediate "alarm reaction" and longer "Training Response" to stress shows that the physical and psychological mechanisms by which the human organism protects itself from being overwhelmed by sudden stresses and prepares itself for future stress shows definite time-relations. In the course of interrogation it has been noted that disorders of function of the kind referred to as psychosomatic are very frequent. The complete unpredictability of the situation so far as the body is concerned appears to lead to a failure of coordination and consecutiveness in the physical responses to mental stress resulting in changes in blood pressure, outbreaks of boils, rashes, etc. The occurrence of these changes in man points the way to experimental confirmation in animals.

Some of the statistical studies which have been made on the effects of detailed psychological treatment suggest that it can achieve little more than would a masterly inactivity on the part of the psychotherapist. Yet we are constantly meeting with instances where relatively brief treatment has brought the patient to a point where his own defences can take over. In the present state of our knowledge chance as well as design play a part in the results we obtain. The effects of interrogation indicate that a brief and intensive approach planned in detail may achieve more than one which is spread over a long period, and also that spontaneous recovery from the effects of psychological trauma is the rule rather than the exception. It may be therefore that conditioning methods and techniques designed to efface self-perpetuating unhealthy mental activity by removing its reference-systems may have a future. This would be no more than using the physician's principle of doing only enough to allow the body's own defence mechanisms to accomplish the rest of the cure. It may be that the lessons of a barbaric assault on the mind may lead us to re-examine some of the established tenets of psychotherapy and so assist in the resolution of neurosis for more civilised ends.

THE SCIENTIFIC LESSONS OF INTERROGATION

EXHIBITS IN THE LIBRARY

An Exhibition of colour photographic reproductions of paintings was shown in the Library with the theme of "The Mind's Eye in Art". The paintings were chosen from three sources, the work of classical and modern artists and that of psychiatric patients, some of whom had no artistic training. Twelve panels illustrated changes in the perception of reality, the effects of mood, of anxiety, of changing attitudes to other people, and of the effects of neurosis and its treatment. Comparisons were shown between painting under the influence of drugs and of schizophrenia and also between abstract and psychotic art in a variety of conventions.

The objective was to demonstrate the use of painting as a language for the communication of subjective feelings, especially those associated with stress, conflict and mental disorders. A panel was also devoted to some artistic productions of nature as seen through the instrumental eye.

The Exhibition was arranged by Professor Alexander Kennedy, Dr. Morris Carstairs and Miss J. O. Harries, the photography being carried out by the Medical Photography Unit of Edinburgh University, under the direction of Mr. T. C. Dodds.

ROYAL INSTITUTION NOTES

THE STRUCTURES OF HAEMOGLOBIN AND MYOGLOBIN

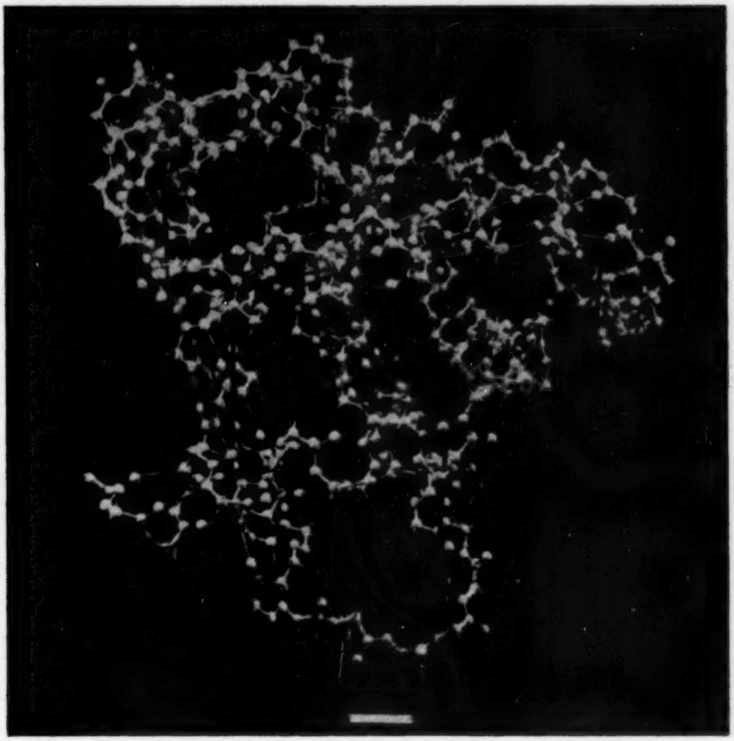
Research Colloquium at the Royal Institution, 29 February, 1960

THE X-ray analysis of the structures of the proteins haemoglobin and myoglobin which has been in progress for many years at the Medical Research Council Unit for Molecular Biology, Cavendish Laboratory, Cambridge, and at the Davy Faraday Research Laboratory of the Royal Institution, has now reached a very exciting stage in which the arrangement of the atoms in the two molecules is becoming clear. Dr. M. F. Perutz, F.R.S., and Dr. J. C. Kendrew, F.R.S., the leaders of the teams engaged in the work, described the recent results to an invited audience of leading scientists at a Research Colloquium held at the Royal Institution on the 29th February, 1960.

The principles of the methods used were described by Dr. Kendrew in a Discourse at the Royal Institution on May 21st, 1958. The procedure is to measure the pattern of X-rays reflected by single crystals of the substances and to use these measurements to calculate the way in which atoms are distributed in the molecules. It is necessary to know not only the intensities of the X-ray beams reflected in different directions, which can be measured directly, but also their relative phases, which cannot. Dr. Perutz showed in 1954 that this difficulty can be overcome by making measurements on several crystals in which small molecules containing a heavy atom have been attached to each molecule of the protein without upsetting the regular arrangement of protein molecules in the crystal structure. The addition of these heavy atoms, usually mercury, changes the intensities of the X-ray reflections slightly and these small intensity changes may be used to determine the relative phases of the X-ray beams. The preparation of the necessary heavy atom derivatives is not at all straightforward and, indeed, it has not been accomplished in the study of any proteins other than myoglobin and haemoglobin.

Model of myoglobin molecule seen at 6 Å resolution. The white rod represents the polypeptide chain; the dark disc is the haem group.

PLATE I



Model of myoglobin molecule seen at 2Å resolution. The individual turns of the helically coiled polypeptide chain can now be distinguished.

PLATE II

Accurate measurements of very many X-ray reflexions from all the crystals are needed to produce a detailed picture of the molecular structure. The calculations which take these measurements into account can be handled only by means of large electronic computers. Chiefly because of the problems involved in making the measurements and handling the data and the results, the analyses have been planned to proceed in stages corresponding to different degrees of resolution. The resolution is determined, as with an optical microscope, by the range of reflexions which are included in formation of the image so that a low resolution image is much more easily obtained than one with high resolution.

The work on myoglobin was described by Dr. Kendrew. Myoglobin is a respiratory protein, the function of which is to store oxygen in the muscle tissue. It is closely related to haemoglobin, the red pigment which transports oxygen in the blood. The tissue of diving mammals is particularly rich in myoglobin and the material studied in greatest detail was obtained from sperm whale. The molecular weight is about 17,000 and the molecule contains some 2,500 atoms, most of which form a single polypeptide chain. The remaining atoms make up the haem group, a planar porphyrin ring system with a central iron atom, to which the stored oxygen molecule is attached. The chemical constitution of both these parts was already known in a general way; thus, the polypeptide chain is made up of some twenty different types of amino acid residue which are linked together. The parts of the residues which form the links of the chain are common to the different types, which are distinguished by the composition of their side chains. The object of the X-ray analysis is to find the detailed arrangement of the atoms.

The structural analysis has proceeded in two stages. In the first stage, which was completed about two years ago, 400 reflexions, each measured from six different crystal types to determine the phases, were used to calculate an image of the structure with 6 Å resolution. The principal features of this image were, first, a region of high electron-density which was slightly flattened in a way consistent with its representing the haem group and, second, a complicated pattern of curving rods of high density, linked together by regions of lower density. This system

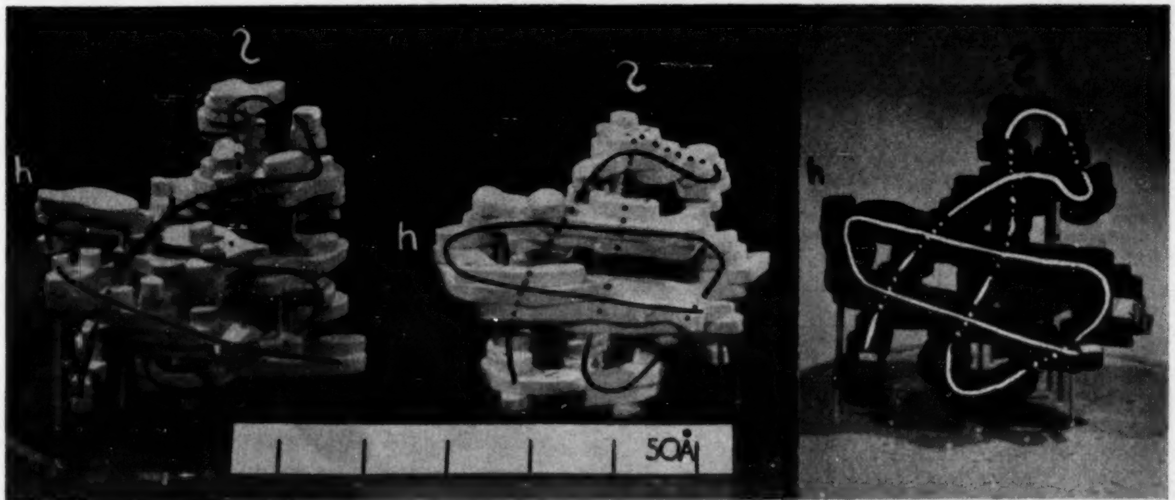
was thought to represent the polypeptide chain coiled up into a tight helix, except at corners where the helical arrangement was upset. The principal features of this image are shown in Plate I.

At this stage, the structure of sperm whale myoglobin was compared with that of seal myoglobin, determined in projection by Dr. Helen Scouloudi, who showed that the molecules from these two different species are very closely the same. This interesting result shows, among other things, that molecules of myoglobin have a well-defined configuration which is retained in two very different crystal structures.

The second stage of the work has involved the measurement of about 10,000 reflexions from each of five different crystal types and has given an image with 2 Å resolution in which the structure of the molecule can be be seen in much greater detail. Separate atoms, which are generally about 1.5 Å apart, still are not quite resolved but many atomic groups can be recognised. In particular the individual turns of the helix can be distinguished and about 70% of the polypeptide chain is seen to be present in the alpha-helical configuration suggested by Pauling, Corey and Bransom. The helix is right-handed, made up of *l*-amino acid residues with known absolute configuration, and its amino and carboxyl ends can be distinguished. Many of the residues can be identified from the distinctive shapes of their side chains even though the individual atoms in them are not resolved, and the structure of the haem group is clearly revealed. It is also apparent that the haem group is attached to the polypeptide chain mainly by a bond from the iron atom to the nitrogen of a histidine residue, though hydrogen bonding from the propionic acid side chains of the haem group to other residues is also involved. Plate II is a photograph of a model of the polypeptide backbone chain and the haem group.

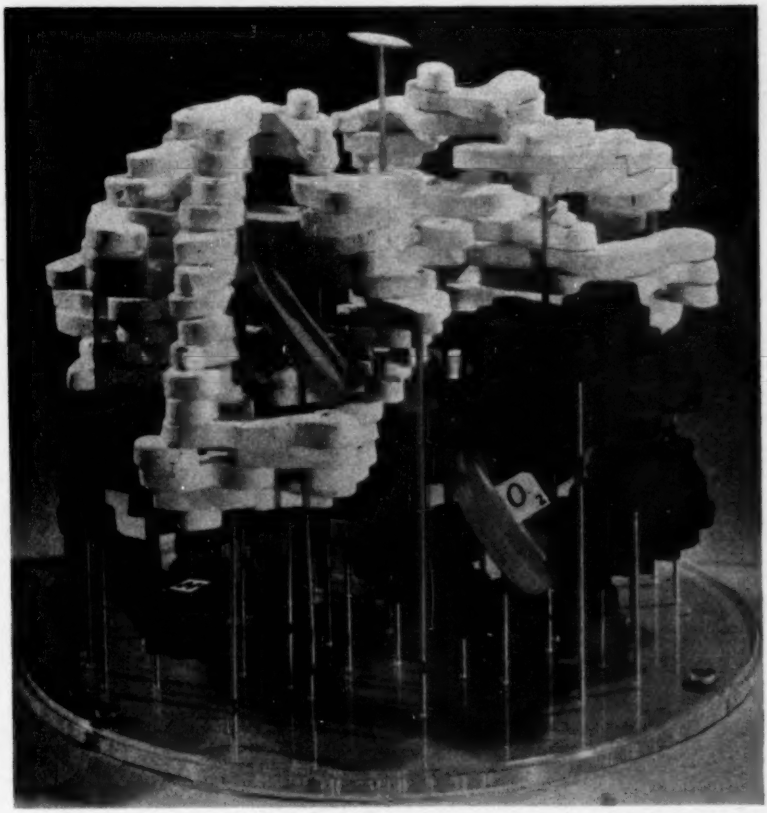
Analysis of the image is still in progress and at the same time work is being begun on the final stage, aimed at the highest possible resolution.

Dr. Perutz described the work on haemoglobin which has a molecule four times as big as myoglobin, made up from four haem groups and four polypeptide chains which are identical in pairs. This work has now reached the low resolution stage,



Models of the myoglobin molecule (on the left) and of the two non-identical chains of the haemoglobin molecule (centre and right) showing the marked general similarity of chain folding. (Reproduced by permission of the Editor of *Nature*).

PLATE III



Model of the complete haemoglobin molecule seen at 5.5Å resolution, showing the fitting together in pairs of the two types of chain. (Reproduced by permission of the Editor of *Nature*).

PLATE IV

roughly corresponding to the first stage of the work on myoglobin, at which the general arrangement of the coiled polypeptide chains and the haem groups can be seen. The image was calculated from measurements of 1,200 reflexions from each of seven types of crystal.

In this image four regions of high density stand out from the rest clearly representing the haem groups. Around these groups there are again more or less cylindrical rods of high density curved to form intricate three-dimensional figures. Analysis has shown that these rods make up four separate units which are identical in pairs. Each unit represents one of the polypeptide chains and the most important result is that the non-identical chains are not only closely similar to one another but that they are closely similar to single molecules of myoglobin. Plate III shows models of the myoglobin molecule and of the two haemoglobin chains.

The four units are arranged roughly tetrahedrally, as shown in Plate IV. The four iron atoms lie in separate pockets on the surface of the molecule and are at least 25 Å apart. There are indications that sulphydryl groups provide linkages between pairs of sub-units.

Work is also being begun on the next stage of analysis of haemoglobin and it seems certain that the structures of both these molecules will soon be known in complete atomic detail. In addition, as Sir Lawrence Bragg, who was Chairman of the meeting, remarked, it seems very likely that general principles of the molecular architecture of proteins will be revealed and that the structures of still larger molecules, perhaps even the viruses, will be determined in similar detail within a fairly short time.

A. C. T. North
D. C. Phillips

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